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The Impact of Green Financial Agglomeration on Sustainable Development in China: Analysis Based on Regional Heterogeneity and Pathway Mechanisms

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Abstract: Based on the panel data of 30 provinces in China from 2012 to 2020, the degree of green financial agglomeration is measured by location entropy, and the spatial diffusion and polarization effects of green financial agglomeration on sustainable development (SD) are analyzed by using the double-fixed spatial Durbin model. By testing the intermediary effect of green technological innovation and the threshold effect of green financial agglomeration, this study confirms the impact of green financial agglomeration on SD. The study demonstrates that green financial agglomeration's impact on economic quality development can be evaluated from a regional heterogeneity perspective. Specifically, in the eastern region, the green financial agglomeration exerts a significant polarization effect on the economic quality development of neighboring regions, resulting in a negative spatial spillover effect. In contrast, the central region has not yet exhibited a spatial spillover effect, while the western region's green financial agglomeration has a noteworthy diffusion effect and a positive spatial spillover effect, significantly promoting the economic quality development of the neighboring regions. Moreover, the study identifies that green financial agglomeration in both the eastern and western regions can enhance economic efficiency and contribute to SD through green technological innovation, as analyzed through the path mechanism. Notably, there is a non-linear relationship between green financial agglomeration and SD.

Keywords: green financial agglomeration, green technology innovation, sustainable development, spatial

1. Introduction

Globally, sustainable development (SD) has become an urgent and essential agenda. With global challenges such as climate change, environmental pollution, and scarcity of natural resources becoming increasingly prominent, governments and businesses are striving to find innovative ways to harmonize economic development and environmental protection. Against this backdrop, green finance has attracted widespread attention as an emerging financial model and instrument. Policymakers, recognizing the potential of green finance for SD, have actively adopted various policies and measures to promote its growth. International financial institutions and multinational corporations have also increased their investment in SD, prioritizing green finance. Relevant policy recommendations have also been made domestically, with the 20th National People's Congress emphasizing that while China is on track for SD, it has yet to achieve its desired goals and must accelerate the process by targeting green, low-carbon industries. In this transformation process, finance is embedded in the development strategy, bringing its capital support into play. The 20th National People's Congress emphasized that although China is on track for SD, it has yet to achieve its desired goals. It must accelerate the process by targeting green and low-carbon industries. In this transformation process, finance is embedded in the development strategy to leverage its capital support. Green finance is a prerequisite for sustainable financial development and has far-reaching implications in promoting the green transformation of the economy. China has made clear the top-level design for building a green financial system, proposing that green finance occupies an important position in building ecological civilization and SD and is a vital link connecting economic development and environmental protection [1–5]. However, despite the progress made in green financial agglomeration, some challenges and obstacles remain. For example, the current focus on green finance needs to pay attention to the economies of scale brought about by agglomeration. Scholars have yet to propose a concept related to green financial agglomeration, and there needs to be more literature on the mechanism of green finance's contribution to SD and the relationship between the two. This paper aims to conduct a qualitative and quantitative study of green financial agglomeration

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through a comprehensive literature study and assess its contribution to SD goals. Based on the perspective of regional heterogeneity, we explore the impact of green financial agglomeration on SD and analyze the regional development variability, address the current development status, and propose corresponding policy recommendations and solutions to promote its better growth and application. Through this study, we hope to provide valuable references and guidance for academic research and practice in related fields and promote the realization of SD.

2. Literature Review

2.1. The concept of green finance agglomeration

Green finance refers to financial services provided by financial institutions that prioritize ecological safety when carrying out economic activities such as credit and securities and only seek to strike an inherent balance between the environment and the economy. For example, banks set financing thresholds for those needing corporate capital, guide production enterprises to establish green industrial lines, and direct social money from energy-intensive and polluting areas to energy-saving and environment-friendly businesses [6]. "The 13th Five-Year Plan" sets out the general guidelines for promoting the development of green finance. The State Council has approved the "five provinces (regions) and eight cities" pilot areas for green finance in China and has made a general layout to promote green finance practices in practice. Along with the gradual advancement of the policy, the pilot areas for green finance reform have taken shape, and the phenomenon of regional financial resources agglomeration has emerged. In other words, financial institutions have made internal and external regional links closer and closer through information sharing and resource swapping, causing external financial enterprises and financial activities to concentrate in a specific region [7–11]. In green economic agglomeration, the main actors involved in green financial behavior and environmental protection integrate into the overall context, collaborate in regional development, and drive change.

2.2. The concept of SD

Giddings et al. [12] point out that "SD" is a vague concept that can take on different "derivatives." Jenkins [13] argues that SD aims to address issues such as biodiversity and climate change through cross-sectoral collaboration across geographies and sectors (e.g., financial, political, transport, etc.). The World Commission on Environment and Development defines SD as development that meets the subsistence needs of the present without compromising the ability of future generations to meet their subsistence needs [14–16]. Macro-regulation supports SD by upgrading the industrial structure of enterprises and innovating industrial technology. At the same time, micro-factors constrain it, such as the current level of product development in China and the laws and regulations enacted by the relevant state departments [17–19]. Therefore, scholars have mainly cut from three perspectives, namely social, economic, and resource environment, to construct a SD evaluation system and measure its impact. Coscieme et al. [20] argue that achieving the goal of SD requires achieving sustainability and systemic coherence and therefore propose that the level of regional SD, sustainability, and systemic coherence are the triangular framework for the quantitative evaluation of regional SD.

2.3. The impact of green finance on SD

Current research mainly focused on the selection and measurement methods of green finance and SD-level measurement indicators and the impact between the two. Lin et al. [21] started from the new development concept and constructed an evaluation index system of SD from three aspects of resource protection, ecological protection, and economic growth and showed the current stage of SD in Suzhou through data. He et al. [22] measured the level of green financial development from four aspects of green credit, green bonds, green insurance, and green investment combined with the expert scoring method. Regarding direct impact, He et al. [22] measured the level of green financial development in four areas: green credit, green bonds, green insurance, and green investment. Regarding direct impact, He et al. [22] and Wang and Li [23] used principal component analysis to verify that green finance has an immediate positive effect on SD. In terms of indirect influence, Lin et al. [24] suggest that guiding the public, enterprises, and the state to join green finance activities, which in turn triggers the renewal of economic and industrial structures, contributes to SD and promotes the two aspects of regional economy and environment to reach a balanced state. Ma [25] suggests the rational allocation of the three resources of humans, capital, and technology in the Greater Bay Area. Ma [25] and Fu et al. [26] argue that a reasonable allocation of human, capital, and technology resources in the Greater Bay Area can trigger the mechanism of interaction between green finance and SD, thus achieving complete coordination. Du et al. [27] and Xiong and Sun [28] explore the role of green finance on SD from three aspects: green consumption of residents, upgradation of industrial structure, and technological innovation of enterprises. Scholars have explored the mutual influence relationship between green finance and SD levels from multiple dimensions, angles, and groups. Still, more literature is needed to consider the financial agglomeration phenomenon and explore the relationship between green economic agglomeration and SD.

The above studies show that there needs to be more literature exploring the relationship between green financial agglomeration and SD. China has implemented a green finance strategy and vigorously developed environmental finance, with a smooth flow of financial resources between regions. The result of green finance in Beijing, Zhejiang, Guangdong, and other areas has taken shape [29, 30]. These regions have used their advantages to bring financial resources and emerge as green financial agglomerations. Still, the agglomeration in some parts may reduce the resources available to other areas. This paper, therefore, proposes the following hypothesis: there may be diffusion and polarization effects of green financial agglomeration on SD [31, 32]. The diffusion effect refers to the fact that green financial agglomerations may have a diffusion effect. The diffusion effect refers to the significant contribution of green economic agglomeration to SD. China has been implementing three effective green monetary policies since 2006. At the early stage of development, it relies more on policy guidance and regional resources, which are mainly devoted to green economic development. Internal agglomeration, to a certain extent, will produce a spillover effect, affecting the development of the surrounding areas. The polarization effect refers to the negative impact of green financial agglomeration on SD. The agglomeration of green finance is a process of quantitative accumulation, which will inevitably produce qualitative changes when it reaches a certain level. Based on this, this paper explores

the possible diffusion or polarization effect of green financial agglomeration on SD from the spatial structure and territory perspective. It analyzes the path mechanism between the two.

3. Theoretical Hypothesis

1) Green financial agglomeration has a direct effect on SD

Optimal allocation of financial resources can only achieve China's SD. Green finance offers a range of financial tools and products to high-pollution and high-energy-consuming enterprises, providing personalized financial services to help reduce environmental pollution and enhance environmental protection. Gradually eliminating inefficient enterprises from the market and raising the financing threshold for high-polluting and high-energy-consuming enterprises facilitate gathering production factors such as human, financial, and material resources in green industries. The development of green finance has resolved the contradictions between China's economy and the environment by redirecting capital from the "two high and one leftover" industries to green industries, which enhances environmental quality, encourages green technological innovation, reduces energy dependence, and ultimately leads to the realization of the "golden mountain, silver mountain, and green water and green mountain" parallel. Based on this, this paper proposes the following research hypothesis:

H1: Green financial agglomeration has a direct role in promoting sustainable development.

2) Spatial spillover effect of green financial agglomeration on SD

Traditional finance and the real economy form the foundation of green finance, and crucial economic and spatial factors determine its development. Regional green finance derives its product from two primary sources: industrial agglomeration and policy platforms.

Green industry agglomeration promotes resource sharing and synergistic effects among upstream and downstream enterprises, realizes economies of scale and scope, reduces transaction costs and enterprise costs, improves labor efficiency, enhances productivity, and boosts the development of the real economy. Simultaneously, regional policies have spatial effects on green finance. The government plays a leading role in promoting the development of green finance in China. The financial policy of China aims to build an integrated national green finance market, promote green finance policy formulation at the federal level, and establish green finance information-sharing mechanisms. The integrated design of various green finance platforms, standards, and tools creates a favorable development environment for local green enterprises, radiating its impact on neighboring regions and building an interconnected green finance market. The development of regional green finance generates strong positive externalities and promotes SD. This paper proposes the following research hypothesis based on the above information.

H2: The promotion effect of green financial agglomeration on sustainable development has a spatial spillover effect.

3) Analysis of the mechanism of the pathway of green financial agglomeration for SD

Green technology innovation is essential for transforming and long-term development of corporations with high energy consumption and high pollution. To achieve the "double carbon" goal, China needs to provide increased support for developing green and low-carbon industries, research and development of technology, and transforming high-polluting and high-energy-consuming enterprises through tax policies related to carbon emissions. Enterprises face substantial risks due to significant initial capital investment, long revenue cycles, and high uncertainty associated with green technology innovation, making them reluctant to engage in green technology research and development. Therefore, the development of green finance is significant in supporting enterprises' green technology innovation. Green finance primarily serves the clean energy industry, strictly screening the pollution level of enterprise projects in the financing process and inhibiting loans to polluting enterprises that do not meet the requirements. Highly polluting and energy-consuming industries that want financing support must adjust their industrial structure through technological upgrading to become eligible loan enterprises and receive funds. Green finance makes up for the financing gap in transforming highly polluting and energy-consuming enterprises by providing funds, relieving the cost pressure of research and development, and building a team of talented individuals in the development process, enabling enterprises to invest more in production and talent acquisition. The availability of funds through green finance helps enterprises to improve their technical level and independent research and development capabilities, leading to the design of projects more in line with the concept of green development. Green technology innovation will not only bring quantitative growth to the economy but also fundamentally change the way the economy grows, achieving a win–win situation for economic development and environmental protection. Based on this, this paper proposes the following research hypothesis.

H3: Green financial agglomeration can indirectly promote sustainable development by supporting green technological innovation.

4. Research design

4.1. Spatial econometric models

4.1.1. Spatial autocorrelation test

To examine the spatial autocorrelation of green financial agglomerations, we calculate the Moran's "I" index, a global Moran index introduced in the mid-20th century that assumes some correlation between things that are close together in spatial proximity [33–35]. Among other things, the global Moran index captures the spatial interdependence of variables [36, 37]. It is calculated as:

$$Moran'I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{1}$$

In Equation (1), $S^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2$, and x denotes the value of the local variable. W_{ij} is the spatial matrix. The Moran index takes matters in the range [−1, 1]. The larger the absolute value, the stronger the correlation between regions.

4.1.2. Spatial weighting matrix design

In this paper, the neighborhood weight matrix (W) is used. The specific expressions are:

$$W = \begin{bmatrix} \omega_{11} & \cdots & \omega_{1n} \\ \vdots & \ddots & \vdots \\ \omega_{n1} & \cdots & \omega_{nn} \end{bmatrix} \quad (2)$$

In Equation (2), the element W_{ij} in W defines the position of two objects in the space, $W_{ij} = 1$ if the two regions are adjacent, and $W_{ij} = 0$ if the two regions are not contiguous.

4.1.3. Spatial econometric model construction

The general form of the spatial panel model is

$$Y_{it} = \alpha I_n + \rho W Y_{it} + \beta X_{it} + \theta W X_{it} + \varepsilon_{it} \quad (3)$$

$$\varepsilon_{it} = \lambda W \varepsilon_t + \nu_{it} \quad (4)$$

In Equations (3) and (4), Y_{it} is the explanatory variable, I_n is the unit matrix, X_{it} is the explanatory variable, α is the constant term, W is the spatial weight matrix, ρWY_{it}, and θWX_{it} are the spatially lagged terms of the explanatory and explanatory variables, respectively, ρ, θ and λ are the spatial autoregressive coefficients of each time, and ϵ_{it} is the error term [26].

4.2. Mediating effect model construction

Through constructing a mediating effects model, this paper verifies that green financial agglomeration transmits SD through the influence of green technological innovation. In response to existing research, green technology innovation can lead traditional industries to change their production structure, upgrade their production, and force industrial enterprises to transform green. Therefore, this paper constructs the following mediating effect model:

$$QUAit = a_0 + \alpha_1 LQ_{it} + \Sigma\delta_i Ctrl_{it} + \grave{O}_{it} \quad (5)$$

$$TEC_{it} = \beta_0 + \beta_1 LQ_{it} + \Sigma\delta_i Ctrl_{it} + \grave{O}_{it} \quad (6)$$

$$QUAit = \theta_0 + \theta_1 LQ_{it} + \theta_2 TEC_{it} + \Sigma\delta_i Ctrl_{it} + \grave{O}_{it} \quad (7)$$

In Equations (5) to (7), SD_{it} is the economic quality development, LQ_{it} is the green financial agglomeration, TEC_{it} is the green technological innovation, Σδi $Ctrl_{it}$ is the sum of the products of control variables and their regression coefficients. α_0, β_0, and θ_0 are constant terms and ϵ_{it} is a random disturbance term [38–40].

4.3. Threshold effect

$$QUA_{it} = \alpha_0 + \beta_1 LQ \cdot I(thre_{it} \le \gamma) + \beta_2 LQ \cdot I(thre_{it} > \gamma) + \beta_n X + \varepsilon_{it} \quad (8)$$

SD is the sustainable development, *LQ* is the green financial agglomeration, *I*(-) denotes the indicative function, there denotes the threshold variable, and denotes the threshold value, and *X* is the control variable.

4.4. Selection of variables

4.4.1. Explanatory variables

Using the entropy value method to determine the weights of each indicator, we referred to the study by He et al. [22], Zhang and Wang [41], Liu et al. [42] and Hu et al. [43]. We used SD as the explanatory variable.

4.4.2. Core explanatory variables

The core explanatory variable is green financial agglomeration (LQ). Referring to Yu et al. [36] and Yu et al. [37] to construct a green economic agglomeration indicator system, the objective weighting method requires a large enough data sample and does not reflect the fundamental importance of the indicators since the accurate weighting method requires a large enough data sample and does not reflect the fundamental importance of the arrows. Therefore, the four dimensions are assigned 45%, 25%, 15%, and 15%, respectively, according to the significance of the current development of green finance in China and the importance of the four dimensions by combining the expert scoring method and then calculating the green financial agglomeration degree using the locational entropy.

4.4.3. Mediating variables

The mediating variable is the green technological innovation (TEC). Sun et al. [44] argue that companies must first achieve energy saving and emission reduction if they want to renew their industrial structure. This change requires them to shift to green and low-carbon technologies. This change requires a technological shift toward green and low-carbon technologies. Therefore, this paper measures the development of green technology by the number of green invention patents granted in each province of China.

4.4.4. Threshold variables

The threshold variable is the green financial agglomeration (LQ).

4.4.5. Control variables

Based on Liao et al. [45], Hussain and Chen [46], Gao et al. [47], Yumei et al. [48] and Liu et al. [49] research findings and previous literature, we selected the following control variables for this paper, as many factors affect regional SD.

All variables selected for this paper are shown in Table 1. The descriptive statistics for the indicators are listed in Table 2.

4.4.6. Data sources

The data were obtained from the National Bureau of Statistics and various statistical yearbooks, and missing data were interpolated to complete the sample.

5. Results

5.1. Spatial autocorrelation

The values of the global Moran's I index for green financial agglomeration are presented in Table 3.

The paper analyzed the spatial relevance of green financial agglomeration in China by calculating Moran's I index for 2012–2020. The results indicate a range of 0.338–0.447 for Moran's I index, with a mean value of 0.372. All of the values deviate significantly from a random distribution at the 1% level, indicating a correlation between the spatial distribution of green financial agglomeration in China. Although Moran's I index fluctuates slightly yearly, it generally remains stable.

5.2. Choice of the spatial econometric model

The Spatial Dubin Model (SDM) model is selected based on the results of the three tests as shown in Table 4.

In this paper, we calculated the Hausman test value using Stata software, which was 205.83 and significant at 1%. The results

Table 1
All variables and related indicators

	Concept level	Guideline level	Indicator layer	Specific meaning	Polarity
Sustainable development	Economic growth	Speed	GDP growth rate	GDP growth rate	Positive
		Size	GDP per capita	Gross regional product/ year-end resident population	Positive
	Innovative developments	Investment in scientific research	Percentage of R&D staff investment	Number of R&D personnel/year-end resident population	Positive
			R&D investment intensity	R&D expenditure/GDP	Positive
		Scientific output	Technology market activity	Technology market turnover/GDP	Positive
			Patent holdings per capita	Number of patents granted/year-end resident population	Positive
	Coordinated development	Level of urbanization	Level of urbanization and ruralization	Number of urban population/year-end resident population	Positive
		Industrial structure	Degree of industrial sophistication	Tertiary sector output/ secondary sector output	Positive
		Consumption structure	Consumption level of the population	Consumer price index	Negative
		Income structure	Per capital disposable income ratio for urban and rural residents	Disposable income per urban resident/ disposable income per rural resident	Negative
	Green development	Energy consumption	Energy consumption per unit of output	Total energy consumption/GDP	Negative
		Atmosphere	Sulfur dioxide emissions per unit of output	Total sulfur dioxide emissions/GDP	Negative
		Water resources	Wastewater discharge per unit of output	Total wastewater discharge/GDP	Negative
		Forests	Forest cover	Forest cover	Positive
	Open development	Economic openness	Level of foreign dependence	Total foreign direct investment/GDP	Positive
		Cultural exchange	Share of international visitors received	Number of international visitors received/year-end resident population	Positive
	Shared development	Education	Level of educational development	Student–teacher ratio in general higher education	Negative
		Medical	Level of medical services	Number of health personnel/year-end population	Positive
		Transportation	Private car ownership per capita	Private car ownership/ year-end resident population	Positive
		Infrastructure	Number of road miles per capita	Number of road miles/ year-end resident population	Positive
Green finance agglomeration	Guideline level	Tier 1 indicators	Indicator layer	Weighting	Polarity
	Agglomeration	Green credit	Agriculture, forestry and fisheries loans/agriculture-related loans	45%	Positive
		Green bond	Market capitalization of A-shares in the six most energy-intensive sectors/A-share market capitalization	25%	Negative

(*Continued*)

Table 1
(*Continued*)

	Concept level	Guideline level	Indicator layer	Specific meaning	Polarity
		Green insurance	Agricultural insurance income/ gross agricultural output	15%	Positive
		Green investment	Investment in environmental protection/local general budget expenditure	15%	Positive
Intermediate variables	Guideline level	Indicator layer	Abbreviations	Unit	Polarity
	Green technology innovation	Number of green patents	TEC	Individual	Positive
Threshold variables	Green finance agglomeration	–	–	–	–
Control variables	Guideline level	Indicator layer	Abbreviations	Unit	Polarity
	Education input	Education expenditure/GDP	EDU	–	Positive
	Level of government intervention	Fiscal expenditure/ GDP	GOV	–	Positive
	Degree of openness to the outside world	Logging of imports and exports	OPEN	–	Positive
	Industrial structure	Gross tertiary sector/ gross secondary sector	INS	–	Positive
	Marketization	FAN marketability index	MARKET	–	Positive

Table 2
Results of descriptive statistics for the main variables

Variables	Number of observations	Average value	Standard deviation	Minimum value	Maximum value
SD	150	−1.622	0.399	−2.484	−0.542
LQ	150	0.023	0.066	−0.135	0.170
TEC	150	6.25	1.408	0.693	9.211
EDU	150	−3.223	0.327	−3.814	−2.186
GOV	150	−1.407	0.389	−2.124	−0.277
INS	150	0.215	0.379	−0.492	1.657
MARKET	150	7.254	2.088	2.53	11.934

Table 3
Green finance agglomeration Moran index

Year	Moran's I	*P*-value
2012	0.382	0.000
2014	0.353	0.000
2016	0.341	0.001
2018	0.338	0.001
2020	0.447	0.000

Table 4
LM test, LR test, Wald test

Test methods	Test volume	Statistical quantities	*P*-value
LM test	LM – spatial lag	12.27	0.000
	Robust LM – spatial lag	9.71	0.002
	LM – spatial error	19.88	0.000
	Robust LM – spatial error	15.316	0.000
LR test	LR – spatial lag	12.27	0.001
	LR – spatial error	12.28	0.001
Wald test	Wald – spatial lag	12.78	0.000
	Wald – spatial error	12.86	0.000

suggest that the estimates from the fixed-effects model are more stable, leading us to use the fixed-effects spatial Durbin model.

5.3. Regional heterogeneity analysis

Table 5 shows the regression results obtained by combining the adjacency matrix and the bi-fixed spatial Durbin model for the study.

At the national level, the coefficient of green financial agglomeration (LQ) is significantly 0.234, and the coefficient of the spatial lag term (W-LQ) is significantly 1.814, indicating that the diffusion effect is significant, forming a positive spatial spillover effect on the SD of neighboring regions. The findings verify that green financial agglomeration can drive the region's

Table 5
Results of sub-regional Durbin model regression analysis

SD	National	East	Central	Western
LQ	0.234* (0.90)	−0.785** (−2.22)	−0.634 (−1.82)	0.225* (0.52)
EDU	0.315*** (2.60)	0.28 (0.99)	−0.777*** (−5.10)	−0.068 (−0.53)
GOV	−0.206* (−1.63)	−0.38** (−1.97)	−0.625*** (−3.05)	−0.862*** (−5.04)
INS	0.101** (1.17)	0.524*** (6.36)	−0.067 (−0.53)	0.783*** (5.68)
MARKET	0.025* (1.65)	0.14*** (6.27)	0.122*** (4.22)	0.486*** (2.42)
W-LQ	1.814*** (3.27)	−0.377*** (−0.49)	−1.017 (−1.37)	3.135*** (2.95)
W-EDU	−0.234 (−0.90)	0.83* (1.93)	−1.529*** (−4.81)	−0.334*** (−2.02)
W-GOV	−0.015 (−0.06)	−0.52 (−1.54)	0.73** (2.03)	−0.137 (−0.47)
W-INS	0.31* (1.72)	0.339** (2.24)	−0.235 (−0.89)	0.492** (1.91)
W-MARKET	0.502* (0.17)	0.071** (2.3)	−0.023 (−0.34)	−0.025 (−1.14)
R^2	0.7	0.841	0.71	0.668
Log-L	189.93	36.073	62.825	80.46

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

economic growth toward high quality, implying that the increasing degree and growing scale of the agglomeration will lead to higher-quality development in the region and neighboring regions. By comparing the magnitude of the impact coefficients within and outside the area, the economic impact of green financial agglomeration on the part is less intense than on neighboring regions. Secondly, the spatial lag term of the control variables is observed, with insufficient government regulation and investment in education. The coefficients of the spatially lagged terms of industrial structure (INS) and marketization (MARKET) all show positive numbers, which indicates that with the upgrading of industrial structure and marketization in the region, enterprises will transform to green and pursue high-quality development, eventually triggering a butterfly effect to promote high-quality economic growth in neighboring areas [50]. It can effectively promote the rational allocation of material resources, capital, and personnel between regions and advance the SD of neighboring areas.

When compared to the regional level, the spatial spillover effect of green financial agglomeration in the eastern region is −0.785. The coefficient of the spatial lag term is −0.377, which indicates that the polarization effect of green economic agglomeration is significant, showing a negative spatial spillover effect on the region and neighboring regions, hindering the SD of the area and neighboring regions. The polarization effect of green finance agglomeration has a significant negative spatial spillover effect on the region and neighboring areas, impeding these regions' SD. The spatial lag coefficient of the central part is insignificant, indicating that the significant green financial agglomeration has yet to impact the region's economic development. At the same time, it has not formed a spatial spillover effect on other areas. There is no diffusion or polarization effect.

Regarding control variables, marketization remains significant at the national level and under sub-regions, and the coefficients are all positive. The estimated results for the western region are relatively close to the national level. The coefficients of the green financial agglomeration effect in the part of the west are all correspondingly more significant than those estimated for the national level. The government is building six provinces (regions) and nine pilot zones for green financial reform and innovation to implement the national concept of green development. The western area occupies three parts: Guizhou, Gansu, and Xinjiang. Although the western region is less economically developed and less well developed in terms of infrastructure than the eastern and central regions, the positive effect of the spatial diffusion of green financial agglomeration on the area's SD is more prominent. The expected function of green economic agglomeration is well played out [51]. The well-played-out anticipated role of green financial agglomeration is actively contributing.

Table 6 further analyzes the spillover effects. At the national level, green financial agglomeration (LQ) significantly contributes to SD, with a coefficient of 0.233. With the indirect impact, the spatial spillover effect generated by green financial agglomeration is 1.861, reflecting that the level of green economic agglomeration in the region will positively impact the SD of neighboring areas. The empirical results show that green finance can strengthen cooperation among financial institutions, promote technological progress, accelerate the flow of funds, and stimulate rapid economic development through scale and technological innovation, also known as the trickle-down effect [51]. The coefficient of EDU is significant under the direct impact and insignificant under the indirect and total effects, which means that the region's investment in education has contributed to its SD. Marketization (MARKET) has a small but positive coefficient for both direct and indirect effects, implying that increased marketization will further boost economic growth in the region and neighboring areas.

At the regional level, the spatially lagged results for green financial agglomeration in the west are similar to the national results. The coefficients for the green economic agglomeration (LQ) effect in the west are all correspondingly more significant than the national estimates and at the 1% significance level. The coefficient of the spatial lag of green financial agglomeration in the eastern region is −0.907 at the 1% significance level, suggesting that green economic agglomeration in the east dampens the SD of neighboring areas. The eastern part has a developed economy and good infrastructure, but these are the results of sacrificing the environment, and there are still unresolved legacy problems of industrial pollution. The coefficient of green financial agglomeration in the central region is negative but insignificant, indicating that the green financial industry in the central region has yet to form an agglomeration and has yet to have a spillover effect on the SD of neighboring areas. Education investment (EDU) is significantly negative for all three products in the central part, indicating that more investment in education is detrimental to the area's and neighboring regions' SD. Too much investment in education will inevitably neglect economic development. Government intervention (GOV) is primarily insignificant in the western and eastern areas. At the same time, it is significantly negative in the central region under all three effects, implying

Table 6
Sub-regional Durbin model effect decomposition

Variables	National			East			Central			Western		
	Direct effects	Indirect effects	Total effect	Direct effects	Indirect effects	Total effect	Direct effects	Indirect effects	Total effect	Direct effects	Indirect effects	Total effect
LQ	0.233** (0.91)	1.861*** (3.36)	2.094*** (3.35)	−0.907*** (−2.26)	0.653 (0.96)	−0.254 (−0.42)	−0.598 (−1.62)	−0.848 (−1.09)	−1.447 (−1.45)	0.401** (0.97)	2.821*** (2.79)	2.42** (2.1)
EDU	0.304*** (2.96)	−0.241 (−0.86)	0.064 (0.2)	0.129 (0.53)	0.673* (1.82)	0.802* (1.92)	−0.732*** (−4.88)	−1.354*** (−4.15)	−2.086*** (−5.12)	−0.064 (−0.58)	−0.281* (−1.85)	−0.345** (−2.12)
GOV	−0.191 (−1.52)	−0.034 (−0.11)	−0.226 (−0.62)	−0.291* (−1.74)	−0.36 (−1.23)	−0.651* (−1.92)	−0.62*** (−3.31)	−0.612* (−1.86)	−1.232*** (−2.58)	−0.844*** (−4.72)	0.001 (0.00)	−0.844** (−3.15)
INS	0.103 (1.08)	0.324** (2.18)	0.426** (2.31)	0.499*** (6.18)	0.13 (1.25)	0.628*** (4.450)	−0.067 (−0.55)	−0.225 (−0.95)	−0.292 (−0.88)	0.762*** (4.78)	0.311* (1.94)	1.073*** (13.36)
MARKET	0.028* (1.60)	0.003* (0.917)	−0.024 (−0.65)	0.134*** (4.95)	0.017 (0.57)	0.151*** (6.85)	0.124*** (4.26)	−0.038 (−0.74)	0.085 (1.11)	0.047* (1.95)	−0.0282 (−1.21)	0.018* (1.86)
R2	0.7			0.841			0.71			0.668		
Log-L	189.93			36.073			62.825			80.46		
LR test (SAR)	12.27**			11.67**			5.93**			18.61***		
LR test (SEM)	12.28**			10.45**			4.35**			16.10**		
WALD test (SAR)	12.78**			13.10**			8.15**			33.34***		
WALD test (SEM)	12.86**			11.65**			7.35**			25.27***		

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

that too much government intervention will only lead to sluggish economic development in the region and adjacent areas. Marketization (MARKET) has a coefficient of 0.134 under the direct effect in the eastern part, which is economically advanced, and increased marketization is the icing for SD.

5.4. Robustness tests

In this paper, considering the endogeneity issue and avoiding the chance of the previous results, the results of the last analysis regression are tested for robustness by replacing the explanatory variables measured by GDP (SD). As shown in Table 7, the empirical results obtained are consistent with the previous paper in general, with changes in the significance of individual variables, proving that the study's impacts on the mechanism of the role of green financial agglomeration in the quality development of the economy are robust.

5.5. Intermediary effects

This paper analyzes the impact path of green financial agglomeration on SD through intermediary effects, as shown in Table 8.

At the national level, the coefficient of green financial agglomeration in model (1) is 2.282, and the coefficient of green technological innovation in model (3) is significant at 0.252, while the coefficient of green financial agglomeration in model (3) is 0.41 and insignificant. According to Wen Zhongqi's theory of intermediation, it is clear that there is a full intermediation effect, i.e., green financial agglomeration ultimately achieves SD by promoting green technological innovation development.

At the regional level, in the east, the coefficient on green financial agglomeration is significant at 2.525. The coefficient on green technological innovation is effective at 0.253 at the 1% significance level. Still, the coefficient on green financial agglomeration in the model (6) is insignificant, i.e., a full mediation effect. In the west, the coefficient of green economic agglomeration is significant at 3.097. We marked the coefficient of green technological innovation at 0.22.

In contrast, the coefficient of green financial agglomeration in a model (12) is insignificant, i.e., a full mediation effect, so there is a full mediation effect in both the east and west regions. The coefficient of green technology in the eastern region is higher than in the western part. Green technology innovation has a more substantial intermediation effect in the east area. The regression results of the intermediation model in the central region indicate that we have yet to reveal the intermediation effect of green technology in a significant part. It cannot promote economic development through technological innovation, which may be mainly due to the lack of innovation policy support from the government in the region and the overall scale inefficiency, which is insufficient to support the upgrading of the industrial structure in the area [52].

5.6. Threshold effect

This paper uses a threshold effect to test whether there is a linear or non-linear characteristic relationship between green financial agglomeration and SD. It selects green financial agglomeration as a threshold variable, conducts single, double, and triple threshold tests, respectively, and determines the appropriate number of thresholds to be selected.

Table 7
Robustness tests

Variables	National	East	Central	Western
LQ	0.399** (0.121)	−0.389** (−2.36)	0.631 (1.74)	0.888*** (2.99)
EDU	0.038 (0.051)	0.008 (0.09)	−0.145* (−1.92)	−0.059 (−0.72)
GOV	−0.226*** (−0.055)	−0.31** (−0.3)	−0.414*** (−3.05)	−0.543*** (−3.56)
INS	−0.151*** (0.036)	0.214*** (2.35)	−.087* (−1.87)	0.139 (1.22)
MARKET	0.016** (0.007)	−.057*** (−0.59)	−0.012 (−0.51)	0.028** (1.89)
W-LQ	0.382*** (0.121)	−0.028** (−0.07)	−1.32 (−2.29)	0.877* (1.47)
W-EDU	−0.089 (0.079)	−.1098* (−.82)	0.144 (1.48)	−0.094*** (−0.73)
W-GOV	-0.013 (0.102)	-0.0144 (−0.1)	−0.071* (0.43)	−0.709** (−2.19)
W-INS	0.34*** (0.053)	0.411** (2.69)	−0.337*** (-4.83)	0.58*** (3.09)
W-MARKET	0.033* (0.09)	0.023* (1.63)	−0.048* (−2)	−0.01 (−0.64)
R^2	0.955	0.946	0.974	0.9864
Log-L	292.723	110.875	100.387	94.637

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

Table 9 and Figure 1 show that the *P*-value under the triple threshold is 0.463. The *P*-value under the double threshold test is 0.38. Since it fails the significance test, we reject the original hypothesis of a linear relationship when using green financial agglomeration as a threshold variable. The *P*-value under the single threshold test is 0.02 with a significance of 5%, so there is a single threshold effect of green financial agglomeration, indicating that the relationship between green financial agglomeration and SD is a non-linear relationship with the first threshold value of 0.902.

Table 10 shows that when the level of green financial agglomeration is below 0.902, the coefficient is significantly −1.103. When the level of green financial agglomeration is above 0.902, the coefficient of its impact on economic quality development is significantly 0.685, which indicates that green financial agglomeration and economic quality development are non-linear relationships. "When the level of green financial agglomeration is below 0.902, there is a negative relationship with sustainable development that may develop into a polarized state, i.e., the polarization effect." When green financial agglomeration is above the threshold, it promotes SD and creates a diffusion effect.

6. Conclusion

The study draws the following conclusions by exploring the regional heterogeneity and path mechanisms of the impact of green financial agglomeration on SD: First, at the national level, the flourishing development of regional green financial agglomeration is conducive to high economic quality, with significant diffusion effects and positive spatial spillover effects. Second, at the sub-regional level, there is a considerable polarization effect in the eastern region, showing a negative spatial spillover effect on neighboring regions; green financial agglomeration has not yet formed a spatial impact in the central area, while there is a significant diffusion effect in the western area, leading to a positive spatial spillover effect on neighboring regions. Third, the green financial agglomeration in the east and west areas promotes the steady progress of the economy toward high quality through the intermediary outcome of green technological innovation; green technological innovation in the central region does not bring about a driving effect, and the intermediary impact is not significant. Fourth, a non-linear relationship exists between green financial agglomeration and SD.

7. Prospects

This paper has given a qualitative and quantitative study of the concept of green financial agglomeration and investigated the impact of green economic agglomeration on SD based on regional heterogeneity and mechanisms of action. Applying new and emerging technologies and innovations in green finance is becoming increasingly important as technology advances. Future research could focus on the role of emerging technologies (e.g., blockchain, artificial intelligence, etc.) and innovative financial tools in promoting green financial agglomeration and explore their potential and application scenarios in SD. The impact of green financial agglomeration on SD is not limited to the economic dimension but also involves social and environmental dimensions. Future research could further explore the linkages between green financial agglomeration and social impact indicators (e.g., employment, community development, etc.) and environmental indicators (e.g., carbon emission reduction, resource conservation, etc.) and delve into the specific contribution of green financial agglomeration to the achievement of SD goals.

Recommendations

Based on the above conclusions, this paper puts forward the following suggestions:

1) According to the factor endowment of the region, the government should make efforts from both the demand side of green industries and the supply side of green projects, explore industries with development potential in the region, establish a high-quality, high-standard, and perfect green industry system, and build a green project bank to attract more green industries to pour in. Encourage enterprises to develop green financial products, enrich the product range to expand the field of green financial services, and promote the expansion of green financial agglomerations.
2) Attach importance to the development of green industries in the western region, using the agglomeration effect to encourage the efficient development of the region's economy and society while using the diffusion effect to have a profound impact on the production behavior, methods, and layout of the surrounding areas, radiating and promoting the economic and social development of the surrounding regions.
3) Actively encourage the eastern and central areas to optimize their industrial structures and guide the transfer of green industries

Table 8
Results of regression analysis of intermediation effects

	National			East			Central			Western		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Variables	SD	TEC	SD	SD	TEC	SD	SD	TEC	SD	SD	TEC	SD
LQ	2.282*** (0.616)	7.431*** (1.905)	0.41 (0.412)	2.525*** (0.695)	7.672*** (1.988)	0.585 (0.556)	−3.711 (2.287)	−15.073* (7.539)	0.620 (0.786)	3.097** (1.329)	12.287*** (4.001)	0.39 (1.137)
TEC			0.252*** (0.019)			0.253*** (0.036)			0.287*** (0.017)			0.22*** (0.043)
Control variables	Control	Control	Control	Control	Control	Control	Control	Control	Control	Control	Control	Control
Constant term	−1.675*** (0.021)	6.078*** (0.064)	−3.206*** (0.114)	−1.318*** (0.022)	7.082*** (0.064)	−3.109*** (0.253)	−1.567*** (0.110)	6.800*** (0.362)	−3.520*** (0.119)	−2.008*** (0.056)	4.897*** (0.168)	−3.087*** (0.213)
Observations	150	150	150	60	60	60	45	45	45	45	45	45
r2	0.103	0.113	0.647	0.219	0.241	0.628	0.07	0.103	0.904	0.134	0.212	0.515
r2_a	−0.123	−0.11	0.554	0.02	0.047	0.523	−0.169	−0.128	0.876	−0.088	0.01	0.372

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

Table 9
Threshold effect test

Threshold variables	Type of threshold	Threshold	F-statistic	*P*-value	10% threshold	5% threshold	1% threshold
Green finance agglomeration	Single	0.902	28.23	0.020	16.597	18.494	25.433
	Double	0.890	9.89	0.380	19.901	25.470	37.371
	Triple	1.09	10.38	0.463	25.141	30.151	46.954

Figure 1
Threshold estimates for green finance agglomeration

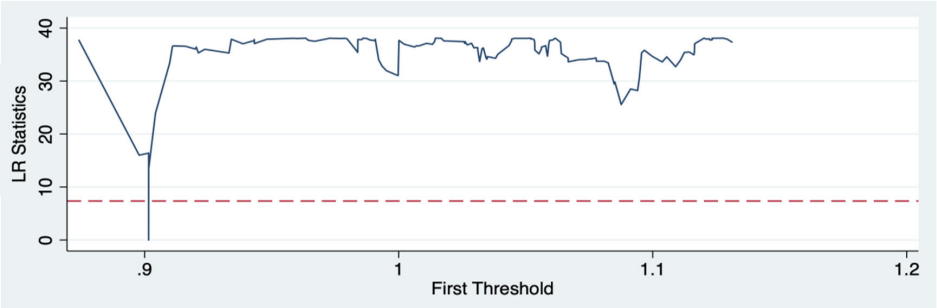

Table 10
Threshold estimation results

Variables	Threshold effect
LQ-I (q<γ)	−1.103***(-2.49)
LQ-I (q>γ)	0.685**(1.68)
LQ	–
EDU	0.807 (0.33)
GOV	−1.148** (−2.28)
INS	0.500*** (8.06)
MARKET	0.065*** (5.28)
Constant term	−3.225*** (−7.14)

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

from the western provinces to the central and east regions to reduce the problem of unbalanced development of industrial agglomeration between areas.

4) Governments, financial institutions, or investors can strengthen the role of green finance to promote the technology of highly polluting and energy-consuming enterprises. Green credit policies that increase the supply of funds can enable enterprises to have sufficient funds to invest in talent training and technological innovation, thus promoting the technology of highly polluting and energy-consuming enterprises. The enterprises can change their traditional production structure and contribute to the central theme of "green water and green mountains are golden mountains."

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Jichao Geng: Conceptualization, Validation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Meng Cai:** Methodology, Formal analysis, Investigation, Data curation, Writing – original draft.

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