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RESEARCH ARTICLE

The spillover effect of green finance development on rural revitalization: an empirical analysis based on China's provincial panel data

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Abstract
With the overall victory of poverty alleviation in China, the focus of rural work has been transformed into rural revitalization. Therefore, based on the panel data of 30 provinces and cities in China spanning 2011 to 2019, this research used the entropy-TOPSIS method to calculate the weights of each index of the two rural revitalization and green finance systems. This research also constructs the spatial Dubin model to empirically analyze the direct effects and spatial spillover effects of green finance development on the level of rural revitalization. Additionally, this research calculates the weight of each indicator of rural revitalization and green finance using entropy-weighted TOPSIS. This research reveals that the current state of green finance is not conducive to increasing local rural revitalization and does not significantly affect all provinces. Further, the number of human resources can improve the local level of rural revitalization, not the entire province. These dynamics benefit the growth of local rural revitalization in the surrounding areas if employment and technology levels are developed domestically. Moreover, this research reveals that education level and air quality have a spatial crowding effect on rural revitalization. Thus, when developing rural revitalization and development policies, it is vital to prioritize the high-quality development of finance to be closely monitored by local governments at the respective levels. Furthermore, the stakeholders must pay critical attention to the connection between supply and demand and between financial institutions and agricultural enterprises in the provinces. Again, the policymakers must also increase policy preference, deepen regional economic cooperation, and improve the supply of essential rural elements to play a more significant role in green finance and support rural revitalization.

Keywords Green finance · Rural revitalization · Spatial effect · Spillover effect

Introduction

Since the 19th communist party of China (CPC) National Congress puts forward the rural revitalization strategy, the construction process has accelerated, and the layout has become more transparent and comprehensive. These

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policies have facilitated the reduction of poverty in the region. Also, the current rural revitalization policies released in 2022 are intended to promote the standardized construction of digital systems in the countryside. Notwithstanding, the outbreak of the coronavirus disease in 2019 (COVID-19) affected the condition at home and abroad, and development has become more uncertain (Oteng Agyeman et al. 2022). Interestingly, several policy interventions have been instituted to fight against the epidemic and restore the general economic and social status in China and the rest of the world (Oteng Agyeman et al. 2022). Also, rural revitalization policies were significantly impacted by the epidemic normalization and the substantial financial, human, and material resources expended in its fight (Somanje et al. 2020; Ma et al. 2021; Oteng Agyeman et al. 2022). Further, the key to rural revitalization helps to simultaneously reduce the 'siphon' effect of cities, directing the flow of talent, technology, and other factors to rural areas and boosting rural development (An et al. 2018; Chen 2019; Mulin and Kui 2021). Therefore, financial support is required to achieve rural revitalization (Shao 2019; Shafi et al. 2020; Xinhua 2022). Research has demonstrated that traditional finance has strong exclusivity and is profit-seeking compared with inclusive digital finance (He and Shen 2021; Liu et al. 2021). Also, digital finance is restricted by natural geographical conditions, making it challenging to meet the demand for funds in rural areas (He and Shen 2021; Liu et al. 2021). Therefore, the introduction of green finance, as an emerging financial instrument, has more substantial technical attributes, lower exclusivity, and lower operating costs than traditional financial instruments (International Institute for Sustainable Development 2015; He and Shen 2021; Liu et al. 2021; Steuer and Tröger 2022). Thus, it suggests that green finance's growth is unquestionably a crucial strategy for transforming China's economic expansion and advancing sustainable development (International Institute for Sustainable Development 2015; Liu et al. 2021; Steuer and Tröger 2022).

This research aims to furnish critical and novel findings on China's rural green financial development, its current trend, and the structure of financial supply, which vary significantly from province to province. Therefore, this research seeks to determine whether the development of green finance in China will dramatically impact rural revitalization. Also, the current study will help determine the direction of the positive or negative effects and their corresponding degree of influence. Furthermore, this research will help examine the spatial interaction linking the variables under study. This research will help to assess green finance's ability to support rural revitalization (Zheng et al. 2021). Again, this research will help reveal the spatial spillover effect between green finance and rural revitalization and their theoretical and practical significance.

Related literature

Research on the level of development of green finance

Green finance, also known as low-carbon finance or eco-finance, has been studied in three stages: germination, rise, and development (Turner 2014; International Institute for Sustainable Development 2015; Owen et al. 2018; Lv et al. 2022). The current research trend helps draw precise and in-depth theoretical and practical knowledge to improve environmental finance and the direction of China's growth of green finance (Owen et al. 2018; He and Shen 2021; Lv et al. 2022). Extant research has defined green finance in a different context, and it has been arguable to reach a conclusive or uniform definition (Turner 2014; International Institute for Sustainable Development 2015; Owen et al. 2018; He and Shen 2021; Liu et al. 2021; Lv et al. 2022; Steuer and Tröger 2022). Further, several scholars have focused on green finance connection to climate change, natural resource conservation and sustainable economic development (Turner 2014; Owen et al. 2018; Agyeman et al. 2022b; Lv et al. 2022). Green finance has been described as a cross-discipline of environmental economics and finance that aims to address the practical issue confronting environmental protection (Cowan 1998). It has also been argued that green finance seeks to achieve sustainable economic development (Cowan 1998; Wang et al. 2021; Wang and Wang 2022). Studies have demonstrated that green finance can directly promote investment growth and indirectly increase corporate investment by adjusting the maturity structure of corporate debt (Owen et al. 2018; Wang et al. 2019, 2021; Agyeman et al. 2022b; Wang and Wang 2022). Research has indicated that green finance policies can have the potential to benefit the environment, primarily by enhancing the industrial structure and intensifying environmental regulations to improve environmental quality (Wang et al. 2019; Ling et al. 2020; Luo et al. 2022). Furthermore, research has revealed a significant gap between China and other nations regarding product segmentation, service scope, and development pace in connection with green finance (Liu et al. 2020; Wang et al. 2021). Notwithstanding, studies have shown that the green finance system is characterized by issues, including an unstructured policy system, insufficient momentum for sustainable development, and a lack of uniform standards (Liu et al. 2020; Tian et al. 2022).

Further, green finance evaluation indicators have been developed to evaluate the environmental protection performance of various financial structures (Liu et al. 2020; Tian et al. 2022). A five-dimensional evaluation indicator of the green finance system was developed to evaluate the level of 34 well-known banks established in Europe and found a positive connection linking green finance and rural revitalization (Jeucken 2010). Also, green finance indicator system trends based on China's economic development were examined to determine the link between green finance and rural revitalization (Jeucken 2010; Lv et al. 2022). Thus, this research emphasized that improving green finance in China will help streamline green finance advancement strategies. Therefore, examining the strong connection between the growth of the financial sector, environmental enhancement, and economic expansion to determine the degree of green financial development in China is fundamental to assessing the green finance system (Jeucken 2010; Chen et al. 2021; Lv et al. 2022; Tian et al. 2022).

Research on the theory of rural revitalization and the realization path

Extant research has explained rural revitalization from the theoretical and practical perspective to reveal the logical and core aspects of rural revitalization, including the strategic thinking and diversified strategic contents of the "three issues of agriculture, the countryside, and farmers" in today''s era, and proposed five specific paths to ensure the smooth implementation of the strategy for revitalizing rural areas (Cairong and Meiqiu 2017). Further, studies have emphasized the pattern of development of urban and rural differentiation in most regions and clarified the five requirements for rural revitalization based on scientific significance and proposed "three paths" to realize the modernization of agriculture, rural area development, and farmers collaboration in the agriculture sector (Zuhui 2018). Also, an analysis of the promotion path of rural revitalization strategy in Guangdong Province was conducted to reveal a structured rural revitalization path suitable for the province acceleration path (Xinrong et al. 2018). An evaluation of how to effectively implement the poverty eradication and rural revitalization strategies was examined in the context of government and market levels to support the agricultural work for rural revitalization through agricultural poverty alleviation measures, infrastructure construction, diversification of land for poverty alleviation, and underwriting (Gao 2019; Li et al. 2022; Ma and Sun 2022). Recent studies have also investigated practical means of promoting and transforming the agricultural industry by optimizing rural governance and literacy to improve the living standards of farmers, as well as new conditions in the field of "three issues of agriculture, the countryside, and farmers (Niya 2021)."

The connection between rural revitalization and green financial development

The effect of financial development and rural revitalization have been examined in diverse jurisdictions with different findings (Shao 2019; Ling et al. 2020; Somanje et al. 2020; He and Shen 2021; Lv et al. 2022). Most of these findings are premised on three perspectives: positive effect, negative effect, and uncertain effect.

Firstly, it is projected that an expansion in monetary advancement can help the country's development (Zheng et al. 2021; Agyeman et al. 2022b). Thus, the gradual improvement of rural financial infrastructure and rural credit capital supply growth may be the critical factors leading to economic progress. Also, in rural development, the optimal allocation of production factors is achieved through the market mechanism when capital drives the flow of other production factors (Xi et al. 2021; Agyeman et al. 2022a; Qian et al. 2022). Studies have shown that financial institutions represented by banks actively develop rural markets, integrate rural financial resources, and guide the other production factors to rural areas to effectively curb the problem of "hollowing out" of rural areas (Jianping and Xiaoguang 2021). Furthermore, the emergence of new rural financial institutions, represented by village banks, is anticipated to supplement rural financial services, ease the outflow of idle funds from rural areas, and inject "start-up" capital for leveraging the rural economy (Xiaoming et al. 2018; Jie 2020).

Further development of green finance may be enhanced through microcredit designed to conform with the requirements of rural business operators who require minimal credit funds to expand with respect to time. A survey of over 1500 rural households revealed a significant connection between trust and informal lending and distrust and formal lending (Turvey and Kong 2010). The findings revealed that microcredit had advantages over informal lending among friends and family (Turvey and Kong 2010). As rural financial development improves, it further reduces credit constraints for farmers based on implemented monetary policies to promote rural revitalization (Abate et al. 2015; Zhichao et al. 2020).

Nevertheless, extant research has revealed that the increase in financial progress may inhibit rural revitalization, while the expansion of financial supply helps rural financial development (Chao and Wei 2021; Xiaozhi et al. 2021). Additionally, it has been established that rural revitalization may be adversely affected by an elevation of the level of rural financial development, which only takes into account the "total" balance and disregards the "structural" balance (Chao and Wei 2021; Xiaozhi et al. 2021). Contrarily, most studies have reached inconclusive or unclear outcomes on how the enhancement of rural economic growth affects the revitalization of rural areas (Turvey and Kong 2010; Abate et al. 2015; Zhichao et al. 2020; Chao and Wei 2021; Xiaozhi et al. 2021). Research has demonstrated that the growth of rural financing may face many realistic dilemmas (Qiong and Jiayu 2021). In solving the deep-rooted contradictions in the rural financial market, stakeholders must improve the financial infrastructure, optimize the credit environment, and reconstruct the rural financial system (Wenbo et al. 2021; Shi 2022). Therefore, policymakers must coordinate several actions to help expand the rural financial market development. Thus, without a comprehensive framework for restructuring the rural financial market, the influence expected on rural financial development would not be achieved.

Motivation for the study

Based on the afore literary works, it has been revealed that the existing research on green finance's spatial spillover effects may serve as a critical point of reference for future research. This research aims to bridge the research gap created on green finance and rural revitalization in the context of China in three dimensions. Firstly, green finance research in China has received little attention. The scanty research primarily focused on conceptual development and failed to conduct rigorous empirical analysis with practical implications. Secondly, few researchers have examined the spatial effects of green finance and rural revitalization without incorporating the framework examining the relationship between these variables. Their findings ignored the spatial interaction effects, which invariably leads to biased conclusions. This research contributes to the existing literature by examining the spatial effects based on rural revitalization and green finance linkages in three critical ways. Initially, this research explores the implementation of rural revitalization policies in provinces and cities across China. It creates a full-featured system of two subsystems of green financial development and rural revitalization. Secondly, this research expounds on the spatial and temporal effects of green financial development on rural revitalization and comprehensively analyzes the framework from the green financial development level. Thirdly, this research considers spatial spillover effects and provides countermeasures for rural finance advancement to encourage rural revitalization while furnishing innovative empirical findings.

The construction of evaluation indicators

Establishing a solid foundation for green finance development is critical to furnish accurate information for analysis. Thus, research on green finance in China is immature, and the scant available research lacks coherence and unstructured data, making it challenging to obtain precise information for an investigation. Based on the undeveloped and immature standards of green finance development, this study develops a green finance indicator system based on four dimensions: green credit, green investment, green insurance, and financial support. Table 1 demonstrates the green finance evaluation indicator system structured for this study.

China's rural development strategy has evolved from "new rural construction → beautiful countryside → rural revitalization," which corresponds to the path of "production development, rich living, civilized countryside, clean village, democratic management → ecological construction, rural governance → eco-friendly industry, affluent life, civilized countryside, and efficient government." Thus, examining the development status of the five dimensions of rural revitalization strategies is critical. This paper refers to the evaluation indicators proposed by the CPC Central Committee and The State Council on Implementing the Rural Revitalization Strategy and the National Strategic Plan for Rural Revitalization (2018–2022) and other relevant research (Mulin and Kui 2021). This study selected 30 level-2 evaluation indicators to construct the rural revitalization indicators based on the measures indicated in Table 2.

Research design

Indicator system construction

Previous studies have examined the comprehensive system of rural revitalization through the application of diverse

Table 1 Evaluation indicator systems for green finance development

First-order index	Secondary index	Indicator calculation	Unit	Nature of indicator
Green credit	Ratio of high-energy industries' interest costs	Six industries that use a lot of energy to pay interest/total industrial interest expenses	%	–
Green investment	As a percentage of GDP, investment in environmental pollution control	Investment in environmental pollution control/GDP	%	+
Green insurance	Depth of agricultural insurance	Income from agricultural insurance/total agricultural output	%	+
Financial support	The proportion of expenditure on environmental protection	Financial environmental protection expenditure/financial general budget expenditure	%	+

Table 2 Rural revitalization indicator system

Indicators at level 1	Indicators at level 2	Indicator calculation	Nature of indicator
Prosperous industry	Agricultural labor productivity	Total agricultural output value/rural population	+
	Degree of agricultural mechanization	Total power of agricultural machinery	+
	Degree of agricultural development	Total food production value/rural population	+
	Rural productivity	Value added of primary industry/gross regional product	+
	Rural industry investment	Year-end productive buildings actual area/rural population	+
	Natural disaster situation	Crop damage area	–
Ecological livability	Renewable energy utilization	Total number of solar water heaters/rural population	+
	Chemical substance input	Standardized agricultural fertilizer application + standardized pesticide use	–
	Degree of village greening	Green coverage	+
	Rural household waste treatment	(Number of domestic waste transfer stations + number of special sanitation vehicles and equipment)/village population	+
	Rural water security	Water penetration rate	+
	Rural toilet hygiene situation	Number of public restrooms	+
Countryside civilization	Traditional virtues of the countryside	Population with divorce status in rural areas/population with various types of marital status in rural areas	–
	Culture and entertainment consumption level	Per capita cultural and entertainment consumption expenditure of rural residents	+
	Educational attainment of farmers	Illiterate population as a percentage of population aged 15 and over	+
	Accessibility of cultural and recreational facilities	Number of comprehensive cultural stations in townships/number of townships	+
	Accessibility of cultural and recreational activities	Average value of combined coverage of rural radio programs and combined coverage of TV programs	+
	Country folk	Village public building construction input	+
Effective governance	Degree of urban–rural income disparity	Rural per capita disposable income/urban per capita disposable income	+
	Degree of urban–rural living disparity	Rural per capita consumption expenditure/urban per capita consumption expenditure	+
	Medical level	Number of village health offices + number of village doctors + number of health personnel	+
	Level of rural poverty	Number of rural residents with minimum living standards	–
	Level of rural land governance	Effective irrigated area	+
	Environmental health construction	Environmental health construction input	+
Affluent life	Income level of rural residents	Net income per capita of rural residents	+
	Consumption level of rural residents	Retail sales of social goods in the countryside	+
	Housing level of rural residents	Residential floor space per capita	+
	Engel's coefficient	Rural residents' food expenditure/consumption expenditure	–
	Public facility construction	Utility construction input	+
	Level of commonwealth	1-incidence of rural poverty	+

methodologies, including the principal component analysis (PCA), multilevel analytic hierarchy process (AHP) method, and entropy value method (Turvey and Kong 2010; Abate et al. 2015; Liu et al. 2020; Wang and Wang 2022). Notwithstanding, these methodologies usually present ambiguous and inconclusive findings and require a high cumulative contribution rate. Also, these methodologies are unable to produce accurate results when the sample size is insufficient, the degree of differentiation is low, and it usually fails to capture the distinctions among evaluation objects. Further, subjective factors influencing weight determination characterize the AHP and some methods (An et al. 2018).

Additionally, when evaluating variables of similar characteristics, the entropy value method does not accurately represent the disparity between actual and expected levels of rural development. Based on the abovementioned reasons, this research broadens and enhances the object of evaluation by incorporating the value formula of positive and negative ideal solutions based on the entropy–weight–TOPSIS (the technique for order preferences by similarity to ideal solution) method (An et al. 2018; Chen 2019; Mulin and Kui 2021). This research further matches the evaluation results with the ideal situation. Additionally, this approach helps to eliminate the drawbacks of the conventional TOPSIS method and the other techniques that primarily rely on expert and personal judgments to establish the weights (An et al. 2018; Chen 2019; Mulin and Kui 2021). This study presents the entropy–weight–TOPSIS method calculation steps as follows:

The first step is the standardization of indicators. This step incorporates both positive and negative indicators for evaluating the degree of rural revitalization. The approach demonstrates that a more significant positive index leads to a higher level of rural revitalization. Also, it is assumed that the smaller the negative index, the higher the level of rural revitalization. In ensuring that the index data are comparable, the positive and negative indexes are treated with dimensionless standardization, and the index value after treatment is between [0,1]. The subsequent equations illustrate the standardized measurement formula.

$$x_{ij}^{\cdot} = \frac{x_{ij} - \min(x_j)}{\max\left(x_j\right) - \min(x_j)} \tag{1}$$

$$x_{ij}^{\cdot} = \frac{x_{ij} - \max\left(x_j\right) - x_{ij}}{\max\left(x_j\right) - \min(x_j)} \tag{2}$$

The proportion of the j indicator in the i year and measured as P_{ij} as expressed in Eq. (3).

$$P_{ij} = \frac{x_{ij}^{\cdot}}{\sum_{\alpha} \sum_{i} x_{ij}^{\cdot}} \tag{3}$$

In the second step, the information entropy of the j th indicator is determined to be the information entropy value. The higher information utility indicator is denoted by d_j. The indicator's importance increases with its weight in the comprehensive evaluation system for rural revitalization.

$$e_j = -k \sum_i P_{ij} \ \ln(P_{ij}), \text{where } k = \frac{1}{\ln(mn)}, \text{ and } k > 0, \text{such that } e_j \geq 0 \tag{4}$$

The redundancy of the j metric's information entropy is calculated in the third step.

$$d_j = 1 - e_j \tag{5}$$

Calculate the weight of the j indicator.

$$w_j = \frac{d_j}{\sum_j d_j} \tag{6}$$

Calculate the weighting matrix.

$$X_{ij} = x_{ij}^{\cdot} \times w_j \tag{7}$$

The fourth step is determining the index's positive and negative ideal solutions. Let V^+ represent the best possible solution and V^- denote the negative ideal solution.

$$V^+ = \left\{\max v_{ij} | i = 1, 2 \ldots, m\right\} \tag{8}$$

$$V^- = \left\{\min v_{ij} | i = 1, 2 \ldots, m\right\} \tag{9}$$

The fifth step is to calculate the Euclidean distance. The positive and negative ideal solutions are set to D^+ and D^-, respectively, in the fifth step.

$$D^+ = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j^+)^2} (i = 1, 2 \ldots, n) \tag{10}$$

$$D^- = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j^+)^2} (i = 1, 2 \ldots, n) \tag{11}$$

The comprehensive score is then determined, as shown in Eq. (12).

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{12}$$

The overall score shows how close the rated object is skewed to the positive ideal solution, also known as the best solution denoted by C_i. It is therefore apparent that $\in (0, 1)$ is ideal for the estimation. Hence, the region's rural revitalization level is closer to the optimal level, closer to 1, revealing the status of rural revitalization in the area. Contrarily, the closer the object is to 0, shows that the rural revitalization level within the region is farther than the optimal level. Hence, the rural revitalization standard is lower and needs further improvement.

Construction of a spatial econometric model

The main models of spatial metrology include the spatial autocorrelation model (SAR), spatial error model (SEM), and spatial Dubin model (SDM) (Afzali-Far et al. 2021). Furthermore, this research projects that the spatial Dubin model can help simplify the spatial lag or a spatial error model. Therefore, the spatial Dubin model with spatial and time-fixed effects best describes the data employed for analysis (An et al. 2018; Chen 2019; Mulin and Kui 2021). Thus, the SDM is a more advanced version of the spatial lag and error models.

$$y_{it} = c + \rho \sum_{j=1}^{n} W_{ij} y_{it} + \alpha X_{it} + \sum_{j=1}^{n} W_{ij} X_{it} \gamma + \mu_i + \lambda_t + \varepsilon_{it} \tag{13}$$

The expression is shown in Eq. (13), where the dependent variable is y_{it}, the independent variable is X_{it}, the coefficient of the independent variable is α, and the constant term is c. The spatial auto-regressive coefficient of the dependent variable is ρ, and γ is the independent variable's spatial lagged coefficient. μ_i and λ_t denote the effects in space and time. The residual term is ε_{it} and the spatial weight matrix is W_{ij}, which shows how each spatial element is related to the other and how much they influence each other. αX_{it} shows how the independent variable affects the dependent variable in the selected regions. $W_{ij} X_{it}$ represents the spatial spillover effect of the local region's independent variable on the neighboring region's dependent variable.

Spatial auto-correlation test

This paper uses the "global Moran's I" index to verify the spatial correlation of the whole panel data. This research uses the geographic adjacency matrix to set the criteria for adjacency.

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (X_i - \overline{X})(X_j - \overline{X})}{\sum_{I=1}^{n} (X_i - \overline{X})^2} \tag{14}$$

Moran's I exponent ranges from (− 1,1). In addition, a value of Moran's I greater than 0 indicates a spatially positive correlation between the observations in the region. The magnitude of this correlation increases with the ideal value.

Data sources and variable descriptions

Research has demonstrated that spatial dependence and correlation make up the spatial spillover effect (Lukongo and Rezek 2018; Afzali-Far et al. 2021). Thus, these subjects of economic activities form spatial dependence under the interaction of space, which results in the spatial correlation of variables between regions (Lukongo and Rezek 2018; Afzali-Far et al. 2021). Also, green financial resources significantly impact mobility and spatial spillover (Lukongo and Rezek 2018; Ju and Ke 2022). Therefore, improving financial development in provinces affects other provinces' financial growth, and the more significant the economic impact, the closer the provinces' geographical connection. Similarly, rural revitalization is perceived to have a spatial spillover effect. A province's good industrial base, convenient transportation, good living environment, and adjacent huge labor market attract more enterprises for investment and drive the development of neighboring provinces through industrial ties, economic ties, and factor flows. Table 3 provides a comprehensive description of the study's variables. Green finance is the core explanatory variable, and the local population, technology, employment, education, and air quality are the control variables used in the empirical research. The comprehensive development level of rural revitalization is chosen as the explanatory variable.

Based on data availability, this research is conducted on 30 provinces and municipalities that fall directly under the authority of the central government and autonomous regions (except for Tibet, Hong Kong, Macau, and Taiwan). Indicators of green finance and the level of rural revitalization are mainly derived from the statistical yearbooks of various provinces from 2011 to 2019. The mean worth strategy is utilized to fill in the missing information. Since data research on green finance and rural vitalization indicators is still emerging, and some data still lack consistency, it makes it challenging to obtain the selected indicators data for analysis.

Table 3 Description of relevant variables

Variables	Variable symbol	Description of the variables	Variable type
Rural revitalization level	Rvl	The above calculation of the comprehensive development level of rural revitalization	Interpreted variable
Green finance	GF	The assessment file framework is built from four aspects: green lending, green investing, green insurance, and support from the government	Core explanatory variables
Population level	Pop	Population birth rate	control variable
Technical level	Tech	R & D personnel full-time equivalent (person-years) in industrial enterprises of above scale	
Employment level	Emp	Employed persons in urban units (million)	
Education level	Edu	The total number of people enrolled in public higher education	
Air quality	AQ	Air quality is expressed in terms of industrial SO_2 emissions	

In order to eliminate heteroskedasticity, the indicators of skill level, employment level, and education level are denoted as lnTech, lnEmp, and lnEdu, respectively. The statistical description of the variables is shown in Table 4 below.

Empirical process and result analysis

Applicability test of the spatial model

This study uses the global Moran index to test the spatial correlation between green finance and rural revitalization variables. The test results of the global Moran index are shown in Table 5.

According to the results in Table 5, Moran's *I* index of China's green finance and rural revitalization level from 2011 to 2019 exhibits positive and significant connections. As a result, it suggests that rural revitalization and green finance have a positive spatial aggregation effect. Therefore, this finding demonstrates the suitability of applying a spatial model for further analysis.

Additional testing and selection of spatial panel models are required to avoid biases in the model setting due to the varying types of spatial panel models. The following are the primary test steps: firstly, this study used the LM statistics to test the autocorrelation between the dependent variable and the spatial error of the spatial lag. Secondly, this research determined and tested how to judge whether the spatial Dubin model will eliminate the spatial error or a spatial lag model through the Wald and LR statistics. Thirdly, this study determined whether the model chooses fixed effect or random effect and whether it needs to use Hausman statistics to determine a better panel effect (Agyeman et al. 2022b). The time-fixed effects model, the spatial fixed effects model, and the spatiotemporal dual fixed effects model are then chosen using the LR test. Table 6 displays the specific results of the model tests.

This paper further uses LM-lag and LM-err statistics to verify the applicability of the spatial model. According to the results in Table 6, the *p* values of LM-lag and LM-err were significant. According to the results, it can be seen that both the SEM model and SAR model are suitable. Therefore, we chose these two models for analysis. In order to ensure that the estimation results of the spatial metrology model are more robust, this study continues to use the LR test for assessment. According to Table 6, both Wald and LR tests significantly reject the two null hypotheses, so the results show that SDM cannot be reduced to the SAR or SEM models. Therefore, the SDM was selected for constructing the model in this paper. Finally, the Hausman test determines whether the model is a fixed effect or a random effect. The test results showed that the null hypothesis was rejected at the significance level of 1%, and the fixed effect model was superior to the random effect. According to the LR test results, both the test results of time fixed effect and space fixed effect reject the null hypothesis significantly. Given this, the SDM model with a bidirectional fixed effect should be selected for the subsequent analysis step.

Table 4 Descriptive statistics of variables

Variable	Obs	Mean	Std.Dev	Min	Max
Rvl	270	0.2373	0.0947	0.1097	0.5555
GF	270	0.1853	0.1082	0.062	0.793
Pop	270	11.2504	2.588	5.360	17.89
lnTech	270	10.6039	1.3574	7.0536	13.3731
lnEmp	270	6.0953	0.7714	4.1043	7.6327
lnEdu	270	7.8177	0.2837	6.9866	8.6328
AQ	270	47.9367	39.2124	0.2672	182.74

Table 5 Global Moran's *I* test result

Year	Green finance		Rural revitalization	
	I	*p* value	*I*	*p* value
2011	0.391	0.000	0.088	0.001
2012	0.381	0.000	0.089	0.001
2013	0.373	0.000	0.084	0.001
2014	0.373	0.000	0.055	0.010
2015	0.370	0.000	0.049	0.015
2016	0.349	0.000	0.045	0.021
2017	0.337	0.000	0.050	0.016
2018	0.379	0.000	0.054	0.013
2019	0.384	0.000	0.080	0.001

Empirical analysis

In this study, the Stata 16.0 software was used to analyze the SDM of bidirectional fixed effects empirically. The empirical results of the model are detailed in Table 7.

Table 6 Spatial econometric model selection test

Panel effect	Quantity of statistics	*p* value
LM_lag	8.808	0.003
LM_lag (robust)	4.723	0.030
LM_error	5.271	0.022
LM_error (robust)	1.186	0.276
Wald_spatial_lag	64.53	0.000
Wald_spatial_error	60.81	0.000
LR_spatial lag	59.90	0.000
LR_spatial_error	633.70	0.000
Hausman test	−10.30	0.000

Table 7 The results of SDM regression

Variable	Random effect	Time fixation effect	Space fixing effect	Double fixing effect
GF	−0.122** (−2.23)	0.135*** (2.6)	−0.1082* (−1.84)	−0.1611*** (−2.91)
Pop	0.0087*** (5.75)	0.0112*** (5.76)	0.008*** (5.45)	0.0064*** (4.81)
lnTech	0.0187*** (2.83)	0.0394*** (5.25)	0.0166** (2.44)	0.0172*** (2.71)
lnEmp	0.0465*** (3.2)	0.0071 (0.55)	0.0441** (2.35)	0.0614*** (3.5)
lnEdu	0.0405* (1.75)	−0.09*** (−4.23)	0.067*** (2.84)	0.0268 (1.24)
AQ	−0.0002*** (−2.74)	0.0003** (2.08)	−0.0002*** (−3.05)	−0.0002*** (−3.55)
W*GF	−0.0549 (−0.24)	0.4057 (1.32)	−0.0453 (−0.21)	−0.6182*** (−2.08)
W*Pop	−0.0204*** (−4.14)	−0.031*** (−2.71)	−0.0205*** (−4.06)	−0.0164** (−1.44)
W*lnTech	0.0831** (2.26)	0.2137*** (4.03)	0.0879** (2.29)	0.1237*** (3.1)
W*lnEmp	−0.2951 (−0.6)	−0.1801* (−1.87)	−0.0272 (−0.57)	0.3276*** (3.01)
W*lnEdu	−0.0426 (−0.5)	−0.1722 (−1.14)	−0.0971 (−1.13)	−0.4491*** (−3.54)
W*AQ	−0.0005* (−1.87)	0.0003 (0.28)	−0.0005* (−1.73)	0.0034*** (4.87)
rho	0.27	−3.28***	0.57	−3.12***
Log-likelihood	607.012	404.373	691.2762	721.2254

*,**, and *** indicate the significance of 0.1, 0.05, and 0.01. The result in parentheses is a Z value

Since there is a spatial slack term of the complimentary factor in the spatial Durbin model, the above-assessed coefficients do not straightforwardly mirror the peripheral impact of the free factor on the reliant variable. However, they are significant at this level. Hence, the impact of the free factor can be decayed into immediate and long-term impacts. The direct effect of the spatial model refers to the influence of the local independent variable on the local dependent variable. In contrast, the indirect effect refers to the spillover effect of the local independent variable on the adjacent regional dependent variable. The decomposition results are shown in Table 8.

The spatial effects decomposition results are shown in Table 8. The results show that (1) green finance exhibits negative coefficients for all the effects. However, only the direct and total effects meet the 1% significance level, indicating that increasing green finance does not improve local rural revitalization. Thus, the negative impact on neighboring areas is not significant. (2) Human resource level. The human resource level has a significant positive coefficient, but only the direct effect is significant above 1%. The exciting finding demonstrates that the level of human resources can only lead to an increase in local rural revitalization, not an expansion in rural revitalization in neighboring provinces.

Table 8 SDM model spatial effect decomposition

Variable	Direct effect	Indirect effect	Total effect
GF	−0.1433** (−2.5)	−0.2805 (−1.54)	−0.4238** (−2.36)
Pop	0.0071*** (5.25)	−0.0129 (−1.98)	−0.0058 (−0.92)
lnTech	0.0142** (2.17)	0.0639*** (2.89)	0.0781*** (3.98)
lnEmp	0.0518*** (2.98)	0.1597* (2.42)	0.2114*** (3.19)
lnEdu	0.0421* (1.92)	−0.276*** (−3.45)	−0.2339*** (−3.09)
AQ	−0.0003*** (−4.51)	0.0021*** (4.43)	0.0017*** (3.72)

*, **, and *** indicate the significance of 0.1, 0.05, and 0.01. The result in parentheses is a Z value

(3) Evaluating the technology and employment levels. The three effects of skill level and employment level are all positive at the significance level of 1%. The exciting finding indicates that the urbanization rate has a significant positive spatial spillover effect. The improvement of local technology level and employment level will benefit the local rural

revitalization and improve the level of rural revitalization in neighboring areas. (4) Assessing the education level. While the indirect spatial effect and the total effect of education level are significantly negative, the coefficient of the direct spatial effect is significantly positive. It suggests a spatial crowding-out effect on the impact of education level on rural revitalization. Thus, the flow of talent makes the competition and crowding-out effect of rural revitalization level among provinces, and the competition among provinces to attract excellent talents forms the migration of labor capital in neighboring provinces. (5) Assessing the air quality level. Air quality level is statistically significant at 1% for all three effects. But the direct effect is negative, while the indirect spatial and total effects are positive. The findings indicate that good air quality promotes rural revitalization in neighboring areas, and bad air quality inhibits local rural revitalization. The finding is vital because environmental pollution emerging from exhaust gas encourages the spillover of local industries or economic agents, further influencing rural revitalization in neighboring areas.

Conclusion and policy suggestions

Building a regional linkage green finance development model

Based on this study's findings, it is established that green financial development in China has strong aggregation and spatial spillover effects, and the development level is characterized by regional imbalance. Therefore, rural capital will be subject to a more significant "siphon" effect from urban real estate and the virtual economy as rural financial development rises. This condition will cause agricultural capital to reverse to the backward flow. As a result, each province should adequately address the unbalanced and inadequate development of green finance among provinces and cities and pay attention to the top-level design. Therefore, there is a need to control the restraining impact on improving rural revitalization in adjoining regions and structure a provincial green finance advancement model with a linkage impact. It, therefore, suggests that China's green finance development disparities should be addressed and linked with other regions to attain progress. Hence, promoting regional and inter-regional green finance's synergistic growth is essential.

Innovating the talent-gathering mechanism for rural revitalization

Based on the rapid development of the rural revitalization strategy in China, part of the rural migrant labor force has become the main force of rural revitalization (Agyeman et al. 2022a). In this context, the countryside should actively establish a talent-gathering mechanism to attain development. Firstly, there should be a framework for developing industrial talent. The country should vigorously promote the project of multiplying local talents and set up a special fund for training practical talents for revitalizing rural industries. Secondly, policymakers should design policies to attract entrepreneurial talents. The countryside should attract foreign workers with entrepreneurial consciousness and modern management experience to assist in developing the region. These entrepreneurs have accumulated rich experience and capital during their years of work in towns and cities. They can significantly contribute to the economic growth of the communities they operate and reside. Therefore, university graduates who have dreams of revitalizing and serving their hometowns may use their knowledge and modern information technology to develop industries in their hometowns. Furthermore, they should encourage upcoming entrepreneurs to relocate to their hometowns and establish businesses. Thirdly, there should be policies for cultivating talents for social governance. Policymakers should implement the "double leaders" cultivation program for the rural party organizing secretaries and use national support policies to actively educate and support young people interested in innovation and entrepreneurship so that they can become the backbone of rural revitalization.

Setting standards for pollutant discharge and rationalizing investment structure in environmental protection

Environmental pollution through carbon dioxide emissions has a negative spatial spillover effect in China's provinces; shifting industries to reduce the pollutants produced is only "a temporary redress" rather than "a drastic measure." As a result, "two high and one surplus" industries must reduce their use of non-renewable natural resources, which leads to pollution, control financial resources, improve resource utilization efficiency, and improve production methods through technological innovation. Simultaneously, industrial pollution source management and investment should be devoted chiefly to controlling or remediating exhaust gas and wastewater in the provinces. Additionally, less attention is paid to production processes and model improvement innovation, resulting in poor pollution control. Furthermore, industrial structure upgrading and optimization have fallen behind. According to the circular economic development principle, source governance is frequently superior to end governance. Thus, a structured avenue for pollution treatment must be implemented, strict regulatory standards for pollutant discharge should be established, and the combination of pollution control and resource utilization should be prioritized for environmental protection. The advancement and optimization of industrial structures and investments in environmental protection are the primary goals of clean technology research, promotion, and application. Based on the constant strengthening and awareness creation of the ecological environment, a fundamental change in the mode of production may be realized. Through the introduction of ecological agriculture, green agriculture, biological pest control technology, and the cultivation of disease-resistant and insect-resistant excellent crop varieties, the impact of pests and diseases on agricultural production is reduced to cut down on the use of fertilizers and pesticides.

Placing much emphasis on culture and leading role in rural revitalization, increasing the amount of money invested in rural education, and raising the quality of rural education

Thus, people's cultural and educational level is projected to promote rural revitalization and pollution control significantly. Based on the nine-year compulsory education in China, cultural popularization, legal propaganda, and technical training should be strengthened for young farmers with low education levels, and the life of rural inhabitants should be continuously improved. Through a collaborated effort of "government + enterprise + society" investment, a high-quality cultural service mechanism that meets the times' requirements and modernizes its management will be built to play its proper role. Thus, enriching rural cultural life provides valuable and healthy food for farmers to meet their daily health and cultural needs. Furthermore, the training of inter-professional talents should be enhanced, and the proportion of multi-talent in the financial industry should be increased.

*Lastly, scientific and technological innovation frameworks should be used to encourage the growth of green industries and deepen the integration of industry, academia, and research (*Li et al. 2021*)* In supporting the development of green initiatives, the most recent scientific and technological achievements should be turned into scientific and technical power. Additionally, scientific and technological methodologies should be utilized to reduce pollutant emissions and solve environmental pollution issues.

Limitations and future research direction

This research focused on the spillover effect of green finance development on rural revitalization in China. The authors selected 30 provinces and cities in China to investigate the impact of green finance and rural revitalization based on panel data from 2011 to 2019 to represent the diversity of China's rural areas. Though the period and coverage are limited, this study is challenged with data availability. Based on data availability, this research is conducted on 30 provinces and municipalities that fall directly under the authority of the Central Government and autonomous regions (except for Tibet, Hong Kong, Macau, and Taiwan). Since data research on green finance and rural vitalization indicators is still emerging, and some data still lack consistency, it makes it challenging to obtain the selected indicators data for analysis. Future studies would be conducted to broaden the examination pattern by incorporating more variables such as infrastructure and social services and the chosen period.

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Data availability All data used for the study are available and have also been referenced in the manuscript.

Declarations

Ethical approval This is not applicable.

Consent to participate This is not applicable.

Consent to publish All the authors have reviewed and approved the manuscript for publication

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