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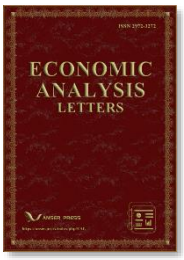

Spatial Effect of Green Finance Development on Regional Green Innovation Efficiency

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ABSTRACT

Green finance is an important driving force to promote green innovation and achieve green development. In order to deeply explore the internal relationship between green finance and green innovation efficiency, this paper selects China's provincial panel data from 2012 to 2023, uses the entropy method and super efficiency SBM model to measure the green finance development index and green innovation efficiency of each province, and on this basis, chooses to construct the spatial Durbin model with fixed effects for empirical analysis and effect decomposition. The results show that: (1) From 2012 to 2023, the development level of green finance and green innovation efficiency of China's provinces will increase year by year with the development of economic base; (2) The green innovation efficiency of provinces with better economic foundation and perfect infrastructure is also at a high level; (3) The level of green finance development, productivity, fiscal revenue and expenditure and urbanization not only have a direct effect on the green innovation efficiency of the region, but also have a spatial spillover effect on the neighboring regions.

KEYWORDS

Green finance; Regional green innovation efficiency; Super-SBM model; The spatial Durbin model

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1. Introduction

In recent years, the concept of sustainable development has gained widespread attention and recognition in the international community. The development of green finance is not only of great significance in addressing climate change, but also provides important support and impetus for economic restructuring and upgrading and the promotion of green innovation. With China's comprehensive deepening reform, the concept of crude economic growth has been replaced by the new development concept of "innovation, coordination, green, openness and sharing". The Chinese government has taken green finance as an important way to promote economic transformation and upgrading and sustainable development. According to data released by the People's Bank of China, by 2022, the size of China's green bond market has exceeded RMB 1.5 trillion, ranking first in the world. However, despite the huge scale of China's green finance market, there are still problems such as insufficient financial financing and inefficient innovative R&D technologies in promoting the efficiency of green innovation in the region, which need to be further studied and explored. Based on this, this paper aims to explore the impact of green finance development on regional green innovation efficiency, so as to provide theoretical and policy support for promoting green economic development and sustainable development.

According to the existing literature, enterprise technological innovation cannot be separated from the financial support provided by financial institutions, and compared with general innovation, green innovation requires greater capital investment and higher risk of R&D failure(Croitoru, 2012). The information asymmetry between green innovation projects and financial institutions often leads to adverse selection and moral hazard, which makes traditional financial institutions often do not invest funds in green projects, and thus there are barriers to the supply of funds. Green finance itself has the nature of public goods, the government through the introduction of green financial policy can provide more appropriate financing options for green investment, to provide solutions to the term mismatch and investment constraints. From the perspective of the relationship between green finance and green innovation, green bond issuance promotes green innovation for enterprises (Flammer, 2021), energy-saving and environmental protection projects require a large amount of capital investment, green funds and green insurance can provide a channel for the entry of private capital (Gilbert and Zhou, 2017), and participation in green insurance can also help enterprises to strengthen environmental risk management (Li and Hu, 2014). Accompanied by the industrialization of enterprises' green technological innovation results, green technology generates innovation compensation effects, which not only provides high investment reports to financial institutions and markets, but also improves the productivity of enterprises and obtains economic returns (Porter and Linde, 1995), i.e., there is a bi-directional evolutionary relationship between technology and finance (Perez, 2009).

The marginal contributions of this paper are: exploring the influencing factors and interrelationships between the level of green finance development and regional green innovation efficiency based on the linkage between the two helps to expand the breadth of green finance research; and the results of the study help the government and enterprises to better formulate relevant policies and strategies to promote the development of the green economy and the practical effects of technological innovation.

The latter paper further explores the spatial spillover relationship between green finance development and regional green innovation efficiency on the basis of existing studies. We collect and organize China's provincial-level panel data from 2012 to 2023, measure the level of green finance development of each province in China by using the entropy method, and portray the green innovation efficiency at the provincial level by using the Super-DEA method, based on which we use the spatial Durbin model to explore the spatial effects between the two.

2. Measurement of core variables

2.1. Indicator system for the level of green finance development

The indicator system of this paper draws on the principle ideas and calculation methods of existing scholars for measuring the level of China's green, low-carbon and recycling development economic system construction, and constructs the green financial development indicator system from green credit, green securities, green investment, green insurance and other aspects respectively, and empirically measures it by using entropy value method. Table 1 shows the meaning of each variable.

Table 1. Indicator system of green finance development.

First-Grade Indicators	Second-Grade Indicators	Method of calculation
Green Credit	Loan scale of environmental protection listed companies	New bank loans of A-share listed environmental protection enterprises/ Loans from banks by A-share listed companies
	Proportion of interest of high energy consumption industries	Interest expense of six energy-intensive industries/total industrial interest expense
Green Securities	Proportion of market value of listed environmental protection enterprises	Market value of A-share listed environmental protection enterprises/total market value of A-share listed enterprises
	Proportion of market value of high energy consuming industries	Market value of A-share listed high energy-consuming enterprises/total market value of A-share listed enterprises
Green Investment	Proportion of investment in environmental pollution control	Investment in environmental pollution control /GDP
	Proportion of fiscal expenditure on environmental protection	Fiscal expenditure on environmental protection/total fiscal expenditure
Green Insurance	Scale environmental pollution insurance	Agricultural insurance income/property insurance income
	Proportion of compensation for environmental pollution insurance	Agricultural insurance expenditure/agricultural insurance income

Among them, the ratio of new bank loans of China's A-share listed environmental protection enterprises refers to the proportion of new bank loans of A-share listed environmental protection enterprises to the loans made by A-share listed enterprises to banks in the current year, and the data is from CSMAR database. The data on the percentage of interest expenses of the six major energy-intensive industries are from the China Industrial Statistical Yearbook. Data related to green securities are from Wind database. The data on agricultural insurance claims expenditure, agricultural insurance premium income and property insurance premium income in green insurance are from China Insurance Yearbook. In order to enhance comparability, some of the data have been calculated twice.

2.2. Indicator system for green innovation efficiency

This paper draws on existing academic research results and chooses the super-efficient SBM model based on unintended outputs, and uses the "Super-SBM NonOriented (Super-SBM-C)" module in the DEA-SOLVER Pro5.0 tool to measure the green innovation efficiency indices of 30 Chinese provinces (except Tibet, Hong Kong, Macao and Taiwan) from 2012 to 2023. In terms of the selection of indicators, this paper considers the indicators from three levels of innovation inputs, innovation outputs and non-expected outputs respectively, and Table 2 shows the explanation of each indicator.

Table 2. Indicator system for green innovation efficiency.

First-Grade Indicators	Second-Grade Indicators	Second-Grade Indicators
Innovative inputs	labor	Full-time equivalent of R&D personnel
	Capital	R&D expenditures
	Energy	Industrial electricity consumption
Innovation outputs	economic effect	Revenue from sales of new products
	Number of innovations	Number of patents granted
Non-expected outputs	environmental effect	Industrial wastewater discharge
		Industrial solid waste generation

The data sources include China Urban Statistical Yearbook, China Science and Technology Statistical Yearbook and China Environmental Statistical Yearbook. Among them, the data on full-time equivalent of R&D personnel, R&D

expenditure, sales revenue of new products and number of patents granted are from China Science and Technology Statistical Yearbook, the data on industrial electricity consumption are from China Urban Statistical Yearbook, and the data on wastewater and waste in unintended output are from China Environmental Statistical Yearbook. The industrial electricity consumption of provinces is calculated by summing up the data of prefectural-level cities because some of them are not shown directly.

3. Analysis of spatial spillover effects of green finance and regional green innovation efficiency

Considering that geographic distance has a major impact on the transaction costs between regions, and that it is usually easier for neighboring regions or regions with shorter geographic distances to overcome the obstacles of spatial distance for communication and transaction, this paper chooses the adjacency matrix (0-1 matrix) to study the spatial effect. And the spatial Durbin model with looser constraints is used in constructing the measurement model, choosing green innovation efficiency as the explanatory variable, green financial development index as the explanatory variable, and the control variables from the three perspectives of productivity level, science and technology expenditure level as well as the level of urbanization, and choosing the secondary indexes such as GDP per capita and the value added of the secondary industry, and the specific variables are shown in Table 3.

Table 3. List of variables selected.

Variable type	Abbr.	Variable name	Unit
Implicit variable	GIE	Green innovation efficiency	%
Independent variable	GFI	Green Finance Index	%
Control variable	GPC	GDP per capita	Chinese yuan
	VSI	Value added of secondary industry	billions
	LR	Local revenues	billions
	GBE	General budget expenditure	billions
	UI	Urbanization level	%
	DUR	Disposable income of urban residents	Chinese yuan

Based on statistical testing and hypothesis verification, including LM test, Hausman test, LR test, the spatial Durbin model constructed in this paper adopts the fixed-effects model, and selects the 0-1 spatial weight matrix to compare and analyze the regression results of the spatial Durbin model (SDM). Model 1 in the following refers to the time fixed effect model, model 2 refers to the individual fixed effect model, and model 3 refers to the two-way fixed effect model combining the two, and the specific regression results are shown in Table 4.

Table 4. Spatial regression effects under three different types of fixed effects models.

Variable	Interactive effect			Spatial effect		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
GFI	0.591***	0.321	0.805	0.563***	0.547**	0.396*
	(4.49)	(0.27)	(0.07)	(1.84)	(2.51)	(1.74)
GPC	-0.271***	0.125	-0.207	-0.171*	-0.851	-0.116
	(-3.33)	(0.16)	(-0.35)	(-1.16)	(-0.83)	(-1.12)
VSI	0.285*	-0.146***	-0.953***	-0.595*	0.798***	0.642*
	(1.67)	(-4.53)	(-4.50)	(-1.91)	(2.90)	(1.96)
LR	-0.173***	-0.168***	-0.298***	-0.214***	-0.221*	-0.488***
	(-5.68)	(-4.90)	(-8.49)	(-2.75)	(-0.34)	(-6.11)
GBE	0.177***	0.257***	0.223***	0.895	-0.205***	-0.216***
	(2.95)	(5.56)	(4.54)	(0.82)	(-3.36)	(-2.60)
UI	0.574***	0.535**	0.135	0.330*	-0.249	-0.146***
	(5.17)	(2.26)	(0.58)	(1.69)	(-0.80)	(-3.57)

DUR	0.127***	0.212	0.228	0.500	-0.909	-0.692**
	(5.46)	(1.13)	(0.12)	(1.14)	(-0.37)	(-2.01)

*Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively, and t-values for each regression coefficient are in parentheses.Model 1 in refers to the time fixed effect model, model 2 refers to the individual fixed effect model, and model 3 refers to the two-way fixed effect model combining the two.*

According to the results in Table 4, it can be seen that the development of green finance both within and between provinces is conducive to promoting the improvement of green innovation efficiency, and there is an obvious spatial spillover effect in its influence. In terms of main and spatial effects, the main effect coefficient of the green finance index (GFI) in the time fixed effect model, individual fixed effect model and two-way fixed effect model is greater than 0, indicating that the development of green finance is able to promote the green innovation efficiency in the region and neighboring regions. The increase in per capita GDP (GPC) and local financial income (LR), on the other hand, show negative coefficients of influence, partly due to the traditional economic production model and the strength of policy support in green innovation. Before the goal of high-quality development was formally proposed, China's economic growth was mainly driven by resource endowment, during which the increase in per capita GDP implied further consumption of resources, affecting the improvement of green innovation efficiency, which led to a negative correlation between the two. At the same time, the improvement of green innovation efficiency needs to be based on the premise of industrial transformation, changing the traditional mode of production to the development of new quality productivity is a relatively long process, in this process requires the policy guidance of the central government and the financial support of the local government, and the source of income of the local government includes the payment of taxes to the enterprise, so it indirectly affects the improvement of the enterprise's green innovation efficiency. The higher the level of taxes, the lower the funds available for green transformation and development, thus hindering the process of green innovation, and the two show a negative correlation.

In order to explore the spatial effect of green finance on regional green innovation efficiency in a more detailed way, the time-fixed spatial Durbin model is chosen here to decompose the effect. Among them, the direct effect represents the influence of green finance development index and other control variables on the green innovation efficiency of the region, while the indirect effect represents the influence of green finance development index and other control variables on the neighboring spatial units, and the specific decomposition results are shown in Table 5.

Table 5. Decomposition of effects in the spatial Durbin model (time fixed effects).

Variable	Total effect	Direct effect	Indirect effect
GFI	0.238***	0.059***	0.179***
	(0.83)	(0.47)	(0.74)
GPC	0.176***	0.044**	0.132**
	(1.10)	(0.74)	(1.01)
VSI	-0.438*	-0.791***	0.353*
	(-0.92)	(-3.97)	(0.82)
LR	-0.242***	-0.200***	-0.041
	(-2.81)	(-5.46)	(-0.53)
GBE	0.163*	0.198***	-0.345
	(1.75)	(4.18)	(-0.38)
UI	0.056**	0.232***	-0.176*
	(0.20)	(1.34)	(-0.65)
DUR	-0.155**	0.037**	-0.192**
	(-0.52)	(0.22)	(-0.70)

*Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively, and t-values for each regression coefficient are in parentheses.*

From the point of view of direct effect, the development of green finance, the increase of productivity level and urbanization level can promote the efficiency of green innovation in the region. GFI, GPC, GBE, UI and DUR positive coefficients indicate that these variables have a facilitating effect on green innovation. Green finance provides financial support for green innovation projects, high productivity level brings technological innovation and knowledge accumulation, accelerates the application of green technology, and the economic structure gradually transforms to green and low-carbon. Local fiscal revenue and expenditure, on the other hand, are negatively correlated with green innovation efficiency, probably due to the fiscal dependence on traditional industries, which leads to insufficient investment in green innovation.

In terms of indirect effects, green finance and productivity levels have positive spatial spillovers on the efficiency of green innovation in neighbouring regions, while fiscal balance and urbanization are negative spillovers. Green finance promotes innovation in neighboring regions through financial support and talent mobility, while regions with high productivity drive innovation in the neighborhood through technological spillovers and supply chains. On the contrary, the siphoning effect of fiscal balance and urbanization may inhibit the improvement of green finance and innovation efficiency in neighboring regions.

4. Research findings and policy implications

4.1. Conclusions of the study

First, on the level of green financial development. Green finance shows a siphoning effect on neighboring regions at the initial stage of development, but with the passage of time and the maturity of the green financial system, it shows a feed-back effect at a later stage. As green finance in the initial stage may choose to focus on investing in more mature and have economies of scale effect of the project, the green finance market in the neighboring less developed regions will reduce the attractiveness and competitiveness. With the maturity of the green financial system and the gradual expansion of the market, the development and growth of green finance in the central region will provide more opportunities for cooperation and resource support for the neighboring regions. Through the establishment of cross-regional cooperation mechanisms and project linkages, green finance in the central region can drive the development of green finance in the surrounding regions.

Second, on regional green innovation efficiency. Spatial effects are influenced by geographic location and the level of regional economic development, and the diffusion and sharing of green innovation efficiencies will be enhanced if there are closer economic ties and resource interactions between neighboring provinces. And the policy and institutional environment is also an important factor influencing the spatial relevance. Government policy support and incentives in the field of green innovation will, to a certain extent, affect the innovation activities and efficiency among provinces, and regions will attract more innovation resources and talents through the introduction of preferential policies or the establishment of green innovation funds and other measures, which will improve the efficiency of green innovation.

4.2. Policy Implications

First, increase green financial policy support. Give preferential tax policies to green finance-related enterprises, set up special funds for the development of green finance or provide financial subsidies for the support of green finance projects and development, encourage financial institutions to increase their investment and financing support for green projects, and guide social capital to invest more in the field of green finance to promote its rapid development. to reduce their operating costs and investment risks.

Secondly, the construction of cross-regional cooperation mechanisms and platforms should be strengthened.

Establishing a green financial cooperation mechanism among provinces, pooling resources to jointly carry out green financial projects, realizing resource sharing and complementing each other's advantages, and promoting cross-regional green financial cooperation. Through the three paths of external incentives, internal motivation and capacity cultivation, we can help the main bodies of the green economic system to exchange funds or information, revitalize green innovation funds, promote the full flow of green knowledge through information exchange channels, and enhance the efficiency of green innovation in the region and neighboring regions through the knowledge spillover effect.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflicts of interest.

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