Pak. j. life soc. Sci. (2024), 22(2): 23442-23464 E-ISSN: 2221-7630;P-ISSN: 1727-4915

Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

https://doi.org/10.57239/PJLSS-2024-22.2.001672

RESEARCH ARTICLE

Nonlinear Effects of Green Finance on Ecological Welfare Performance in Chinese Provinces

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ARTICLE INFO

Received: Aug 15, 2024

Accepted: Oct 19, 2024

Keywords

Green finance
Ecological welfare
Performance threshold effect

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ABSTRACT

This study utilizes provincial panel data from 30 provinces in China, excluding Tibet, Hong Kong, Macau, and Taiwan, from 2000 to 2021. The Entropy Weight Method and the Super Efficiency Slack-Based Measure (SBM) model with undesirable outputs are applied to measure the development of green finance and ecological welfare performance, respectively. Based on these measurements, a threshold regression model and a baseline regression model are established to explore the nonlinear relationship between green finance and ecological welfare performance. The analysis reveals a significant double-threshold effect of green finance on ecological welfare performance, displaying a positive U-shaped nonlinear pattern. Green finance development exerts a nonlinear suppressive effect on the negative impact of environmental regulation and openness on ecological welfare performance. Additionally, green finance promotes the positive impact of innovation levels on ecological welfare performance, though this effect exhibits a nonlinear diminishing trend. The influence of green finance on ecological welfare performance also varies across regions. Accordingly, this paper proposes differentiated policy recommendations for various development stages, aiming to enhance the development of green finance and ultimately improve ecological welfare performance.

INTRODUCTION

Since the implementation of China’s reform and opening-up policy in 1978, the country has experienced rapid GDP growth. However, this swift economic expansion has also led to significant challenges in terms of the sustainability and quality of development, as it has been accompanied by the overconsumption of natural resources and severe environmental degradation. In response, the Chinese government has introduced a sustainable development strategy, implementing a series of policies aimed at promoting economic sustainability. These include the transformation and upgrading of traditional industries, green technological innovation, and the development of new energy sectors, all designed to achieve sustainable growth while reducing resource consumption and environmental pollution. Under this national strategy, China’s economic development model has been shifting from one that prioritizes speed and scale—often at a high ecological cost—toward a more ecologically friendly and low-carbon sustainable model. In this paper, I argue that when analyzing and discussing China's current economic conditions, it is essential to adopt a sustainability-oriented perspective. Such an approach ensures that the resulting research and policy recommendations are better aligned with China's future developmental trajectory, offering greater adaptability and practical significance. This broader macroeconomic context forms the backdrop for the present study.

With the evolution of sustainable development theory and the rise of steady-state economics, Chinese scholars Zhu, D., & Qiu, S. (2008) introduced the innovative concept of "Ecological Welfare Performance" as a tool to measure and evaluate the level and potential of sustainable economic development. This concept encapsulates the relationship between ecological resource consumption, economic growth, and the improvement of social welfare in a coordinated manner. Building on this conceptual innovation, subsequent scholars such as Sun, R. (2022), Liu, N., Zhang, J., & Wang, X. (2021), and Xiao, L., & Ji, H. (2018) have conducted extensive research on China's sustainable development challenges using ecological welfare performance as a metric. Their work has demonstrated the wide applicability and profound influence of this concept in the field of sustainable development in China. This paper contends that sustainable economic development emphasizes the coordinated progress of the economy, social welfare, and the environment, and that ecological welfare performance is an ideal tool for capturing this relationship. Therefore, this study will use ecological welfare performance to measure China's level and potential of sustainable economic development.

In recent years, green finance has emerged as a critical financial mechanism for promoting sustainable economic development (Wen et al, 2022; Chen et al, 2022), and its significance is widely acknowledged. Green finance facilitates the efficient and rational use of resources and energy by attracting capital into green industries and environmental protection projects. In doing so, it supports the green transition of production and lifestyles, enhancing resource efficiency, reducing energy consumption, protecting the environment, and maintaining ecological balance (He, Z., 2024). Moreover, green finance encourages businesses and financial institutions to focus more on Environmental, Social, and Governance (ESG) factors, steering investment decisions and capital flows toward sustainability and fostering long-term sustainable economic growth (Zhou, 2020).

Given the above, this study uses ecological welfare performance as a key metric for evaluating China's sustainable economic development and investigates the impact of green finance on this development. A review of the China National Knowledge Infrastructure (CNKI) database reveals that research on the relationship between green finance and ecological welfare performance is a relatively new field of inquiry. High-quality studies in this area have only started to appear since 2021, and while scholars such as Liu, D., Zhang, F., & Huang, Y. (2021), Tan, Z., Li, M., & Xu, P. (2023), and Shi, J. (2023) have conducted meaningful explorations, there is still much room for deeper investigation. This provides an opportunity for further contributions through the present study.

2. LITERATURE REVIEW

2.1 Concept and measurement of ecological welfare performance

Concept of ecological-welfare performance

The concept of Ecological Welfare Performance originates from the steady-state economics proposed by Daly (1974). Few (1993) emphasized the symbiotic relationship between ecological resilience and economic welfare enhancement, positing that sustainable economic development can only be achieved when welfare levels rise concurrently within an ecologically sustainable framework. Chinese scholars Zhu, D., & Qiu, S. (2008) introduced the concept of "Ecological Welfare Performance," which fundamentally seeks to maximize human welfare enhancement with minimal input and consumption of natural resources. This process involves two core transformations: the conversion of natural resources into economic growth, followed by the transformation of economic growth into human welfare. Unlike traditional economic growth models, Ecological Welfare Performance places greater emphasis on social welfare, aiming for comprehensive development and minimal resource consumption. This reflects an approach to utilizing ecological resources that efficiently and sustainably enhances social welfare.

Indicator System for Measuring Ecological Welfare Performance

Daly's (1974) pioneering work established a foundational approach to measuring ecological performance by calculating the ratio of service flow to throughput. This laid the groundwork for the quantitative analysis of Ecological Welfare Performance. Scholars such as Zhu, D., & Qiu, S. (2008) have utilized the ratio of natural resource inputs to social welfare outputs to assess the level of Ecological Welfare Performance. In terms of natural resource inputs, researchers such as Deng, Y., Wang, Z., and Wang, Z. (2020, 2021) have measured inputs of energy, water, and land resources.

For measuring social welfare levels, the United Nations Development Programme (1990) introduced the Human Development Index (HDI), which consists of three sub-dimensions: health, education, and economic development. As welfare economics has evolved, scholars have developed a more nuanced and comprehensive understanding of social welfare. Researchers such as Wang, Z., & Wang, Z. (2021), Zhu, J., & Pang, W. (2022), and Chen, D., & Liu, W. (2024) have incorporated environmental welfare into social welfare measurements and further refined indicators for economic development, health, and education welfare.

Guo, B., Li, C. (2021), and Li, C. et al. (2019) have argued that while natural resources serve as inputs to ecological capital, outputs should also consider environmental pollution as an undesired output. This perspective is reflected in the work of several scholars. When assessing environmental pollution, researchers such as Long, L., & Wang, X. (2017) and Fang, S., & Xiao, Q. (2019) have employed multi-dimensional quantification, including wastewater discharge, air emissions, and solid waste output. As noted by Wang, Z., & Wang, Z. (2021), such multi-dimensional assessment methods provide a more comprehensive and in-depth perspective on the impact of environmental pollution on Ecological Welfare Performance. This study will develop a measurement indicator system for Ecological Welfare Performance with undesired outputs based on the research findings of these scholars.

Method of ecological welfare performance measurement

The measurement methods for Ecological Welfare Performance primarily include ratio methods, Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA). Compared to ratio methods and SFA, the DEA method offers several advantages: it does not require specifying a particular production function, its indicators are dimensionless, and it can handle multiple inputs and outputs. These advantages make DEA widely applied in the measurement of Ecological Welfare Performance and establish it as a mainstream method for calculating welfare performance. Chinese scholars such as Zhu, D., & Qiu, S. (2008), Long, L. (2019), and Deng, Y. (2020) have employed the DEA method, using resource consumption as inputs and social welfare levels as outputs to measure Ecological Welfare Performance. To address the issue of environmental pollution as an undesired output in Ecological Welfare Performance, the super-efficiency DEA SBM model is increasingly used to calculate comprehensive indices of Ecological Welfare Performance. This study will utilize the super-efficiency DEA SBM model to measure Ecological Welfare Performance across Chinese provinces.

2.2 Concept and measurement of green finance

Concept of green finance

Green finance originated from the U.S. Superfund Act and the infamous "Love Canal" pollution incident. In response to the environmental issues arising from economic development, financial innovations emerged, giving rise to the concept of green finance. According to Salazar (1998) and Cowan (1999), green finance refers to financial tools used by governments and financial institutions to promote ecological protection and sustainable economic development characterized by green and low-carbon approaches. Wang, F., & Wang, K. (2018) assert that green finance falls within the category of financial tools related to environmental policy. Wen, S., Zhang, T., & Li, Y. (2022) and Chen, G., Liu, H., & Zhou, J. (2022) suggest that while definitions of green finance may vary in focus, they generally converge on the concept of financial services aimed at economic sustainability based on ecological protection, efficient utilization of natural resources, and climate change mitigation. In 2006, China provided a national definition of green finance: it is a comprehensive financial service, including investment, financing, project operation, and risk management, aimed at promoting sustainable development through projects related to ecological environmental protection, energy conservation, emission reduction, and climate change mitigation. This definition has received broad recognition and support in Chinese academia, and this study will be conducted based on this definition of green finance.

Indicator System for Measuring Green Finance

The indicators used to measure green finance primarily include green credit, green securities, green insurance, and green investment (Yu, B., & Fan, C., 2022). With the growing focus on carbon emissions and ecological environmental protection and sustainable development issues, an increasing number of scholars have incorporated carbon finance (carbon emission intensity) into the green finance measurement indicator system, forming a classic framework for measuring green finance (Liu, D., Zhang, F., & Huang, Y., 2021; Zhou, B., & Li, Y., 2024). Scholars such as Lin, M., & Xiao, Y. (2023) argue that the development of green finance is closely tied to government actions, and therefore, in their research, they have included green support as an indicator in the green finance measurement system. Additionally, research by Xue, H., & Kan, L. (2024), and Li, J., & Liu, X. (2024) further incorporates green funds into the measurement indicators. Overall, with the advancement of research, the measurement indicator system for green finance has become more comprehensive and scientifically rigorous, allowing for the formation of a more detailed and integrated green finance index. This study will utilize seven specific indicators—green credit, green securities, green insurance, green investment, green funds, green support, and carbon finance—to measure green finance.

Measurement Methods for Green Finance

The primary methods for measuring green finance are principal component analysis (PCA) and entropy weighting method. An increasing number of scholars are adopting the entropy weighting method over PCA to measure the comprehensive index of green finance development (Chai, Z., et al., 2024). Accordingly, this study will employ the entropy weighting method to measure the comprehensive index of green finance.

2.3 Influence relationship of green finance on ecological welfare performance

Impact of green finance on ecological welfare performance

Liu, D., Zhang, F., & Huang, Y. (2021) utilized panel data from 2007 to 2018 and applied a Tobit static panel model for empirical analysis to explore the positive impact of green finance on ecological welfare performance at the provincial level. They further revealed the differences in this impact across various regions through an analysis of regional heterogeneity. Building on this, Liu, X., & Zhuang, X. (2022) used panel data from 171 prefecture-level cities from 2010 to 2019 and applied the Tobit model to confirm that green finance significantly promotes ecological welfare performance in urban clusters. Shi, J. (2023) also confirmed, through static analysis of panel data from 30 provinces from 2011 to 2020, that green finance significantly enhances ecological welfare performance.

While these studies confirm the positive impact of green finance on ecological welfare performance, they all use the Tobit panel regression model to analyze the relationship between green finance and ecological welfare performance. It is important to note that in the application of the Tobit model, some data values of the continuous variable for ecological welfare performance are transformed into

0 or 1, which may lead to the loss of some information on ecological welfare performance variables. Additionally, these studies use data covering a maximum of 12 years, and their conclusions would benefit from validation with longer time series data. Therefore, this study employs the original data for ecological welfare performance, without converting any part of the data into binary values (0 or 1), and uses panel data from 30 provinces from 2000 to 2021 to examine and validate the positive impact of green finance on ecological welfare performance.

Non-linear impact of green finance on ecological welfare performance

Li, S., et al. (2024) examined the impact mechanism of green finance on industrial green development using a threshold regression model and verified that green finance has a significant non-linear threshold effect on industrial green development. Li, J., & Liu, X. (2024) also found a non-linear impact effect of green finance on common prosperity based on a threshold regression model. Furthermore, Guo, B., & Lin, J. (2021) discovered a significant non-linear impact effect of environmental regulation on ecological welfare performance in the Yangtze River Economic Belt. Guo, B., & Feng, Y. (2023) indicated that heterogeneous environmental regulations have a significant non-linear impact effect on ecological welfare performance. Additionally, Xu, W., & Li, L., et al. (2021) found that China's green innovation efficiency has a significant non-linear impact effect on ecological welfare performance. Zhu, M., et al. (2022) observed that green finance exhibits an inverted "U" relationship with ecological efficiency in the Yellow River Basin and a "U" relationship with spatial spillovers in the surrounding cities of the Yellow River Basin.

In summary, existing high-quality literature supports the notion of non-linear impacts of green finance on other variables and the non-linear impacts of other variables on ecological welfare performance. However, there is a lack of literature exploring the non-linear relationship between green finance and ecological welfare performance. This study aims to empirically investigate the non-linear impact relationship between green finance and ecological welfare performance.

3. RESEARCH DESIGN

3.1 Model design

Panel-threshold regression model

Based on the research hypothesis, this study will first employ a panel threshold regression model to examine whether there are nonlinear threshold effects of green finance on ecological welfare performance. The following threshold regression model will be constructed:

$$\mathrm{lnstfl} = \beta_0 + \beta_1 \mathrm{lngreenf} \cdot I(\mathrm{lngreenf} \leq \delta_1)$$

$$+\beta_2 \mathrm{lngreenf} \cdot I(\delta_1 < \mathrm{lngreenf} \leq \delta_2)$$

$$+\beta_3 \mathrm{lngreenf} \cdot I(\delta_1 < \mathrm{lngreenf}) + \sum_{j=1}^{5} \gamma_j \, \mathrm{control}_{j,i,t} + \varepsilon_{i,t} \qquad (1)$$

In the model, $I(.)$represents an indicator function, where,$I(.)=1$,if the condition within the parentheses is true, and$I(.)=0$,otherwise;δ_1和$\delta_2$enotes the threshold value of green finance；β_i（$i = 1,2,3$）represent the regression coefficients for the threshold variables in different intervals of green finance values.；$\mathrm{control}_{j,i,t}$ denotes the control variables.

To further investigate the nonlinear threshold effects of green finance in the context of how control variables impact ecological welfare performance, this study constructs the following panel threshold regression model, with green finance as the threshold variable and various control variables as independent variables.

$$\mathrm{lnstfl} = \beta_0 + \beta_1 \mathrm{control}_{,i,t} \cdot I(\mathrm{lngreenf} \leq \delta_1)$$

$$+\beta_2 \mathrm{lngreenf} \cdot I(\delta_1 < \mathrm{lngreenf} \leq \delta_2)$$

$+\beta_3 \mathrm{lngreenf} \cdot I(\delta_1 < \mathrm{lngreenf}) + \sum_{j=2}^{3} \gamma_j \, \mathrm{control}_{j,i,t} + \varepsilon_{i,t}$ (2)

Baseline Panel Regression Model

If a threshold effect exists in the impact of green finance on ecological welfare performance, to precisely characterize the specific nonlinear effects of green finance on ecological welfare performance, this study utilizes a baseline panel regression model. In the modeling process, the squared term of green finance, lngreenf2 is used to represent the specific impact of green finance. The following model is constructed to examine this relationship:

$$\mathrm{lnstfl}_{i,t} = \gamma + \gamma_1 \mathrm{lngreenf}_{i,t} + \gamma_2 \mathrm{lngreenf2}_{i,t} + \sum_{j=3}^{7} \gamma_j \, \mathrm{control}_{j,i,t} + u_i + \mu_i + \varepsilon_{i,t} \quad (3)$$

In the model, $\mathrm{llngreenf}_{i,t}$represents the level of green finance in province i at time t,$\mathrm{lngreenf2}_{i,t}$denotes the squared term of green finance in province i at time t， $\mathrm{lnstfl}_{i,t}$ indicates the level of ecological welfare performance，u_i denotes the individual fixed effects,$\mu_i$denotes the random effects， $\varepsilon_{i,t}$represents the error term.

Dynamic System GMM Regression Model

To ensure the reliability of the regression results and address potential endogeneity issues during the analysis, this study introduces a first-order lag of ecological welfare performance into a dynamic panel model. The System GMM method is employed to analyze the impact of green finance on ecological welfare performance, facilitating the examination of endogeneity and robustness.

This study examines the dynamic effects of fiscal decentralization on ecological welfare performance, the dynamic effects of green finance on ecological welfare performance, and the combined temporal dynamic effects of fiscal decentralization and green finance on ecological welfare performance. To this end, the study first establishes the following dynamic panel models based on the System GMM method and further employs the Sargan test and Arellano-Bond autocorrelation test to validate the endogeneity and robustness of the regression results.

$$\mathrm{lnstfl}_{i,t} = \alpha + \beta \mathrm{lnstfl}_{i,t-l} + \gamma_1 \mathrm{lngreenf}_{i,t} + \gamma_2 \mathrm{lngreenf2}_{i,t} + \sum_{j=3}^{7} \gamma_j \, \mathrm{control}_{j,i,t} \quad (4)$$

In the model, $\mathrm{lnstfl}_{i,t-l}$represents the lll-th order lag of ecological welfare performance.

3.2 Variable selection

Dependent variable

In this study, the dependent variable is ecological welfare performance. For the specific measurement indicators of ecological welfare performance, this research constructs an indicator system based on the work of scholars such as Long, L., & Wang, X. (2017), Fang, S., & Xiao, Q. (2019), Xu, Y. (2017), Deng, Y. (2020), Chen, D., & Liu, W. (2024), Xiao, L., & Xiao, Q. (2021), Zhu, J., & Pang, W. (2022), and Sun, W., & Wang, Z. (2022). This indicator system is tailored to the ecological welfare performance relevant to this study (see Table 1).

Table1: Indicator system of ecological welfare performance

Primary Indicator	Secondary Indicator	Tertiary Indicator	Remarks
Resource Consumption	Energy Consumption	Per Capita Coal Usage (tons)	Long, L., & Wang, X. (2017)
	Water Resource Consumption	Per Capita Water Usage (cubic meters)	
	Land Resource Consumption	Per Capita Construction Land Area (square meters)	

Welfare Level	Economic Development Welfare	Urban-Rural Income Gap	Chen, D., & Liu, W. (2024)
		Per Capita Disposable Income (Yuan)	
		Per Capita GDP	Xiao, L., & Xiao, Q. (2021)
	Healthcare Welfare	Number of Health Personnel per 1,000 People	Zhu, J., & Pang, W. (2022)
		Number of Medical and Health Institution Beds per 1,000 People	Wang, Z., & Wang, Z. (2021)
		Average Life Expectancy (years)	
	Environmental Welfare	Green Coverage Rate in Built-up Areas (%)	Sun, W., & Wang, Z. (2022)
		Per Capita Park Green Space Area (square meters/person)	
		Rate of Non-hazardous Treatment of Domestic Waste (%)	
	Educational Welfare	Average Years of Education	Long, L., & Wang, X. (2017)
Environmental Pollution	Wastewater Discharge	Per Capita Sewage Discharge (tons)	Long, L., & Wang, X. (2017),
	Solid Waste Emission	Per Capita Solid Waste Discharge (tons)	
	Air Pollution	Per Capita Air Pollutant Emission (tons)	
	Household Waste	Per Capita Household Waste (tons)	Wang, Z., & Wang, Z. (2021)

Core explanatory variables

The core explanatory variable in this study is green finance. For the specific measurement indicators of green finance, this research constructs an indicator system based on the work of scholars such as Yu, B., & Fan, C. (2022), Lin, M., & Xiao, Y. (2023), and Xue, H., & Kan, L. (2024). This indicator system is tailored to the green finance relevant to this study.(see Table 2)

Table2: Indicator system of green finance

Primary Indicator	Secondary Indicator	Operational Definition of Secondary Indicator		Notes
Green Finance	Green Credit	Ratio of Environmental Project Loans to Total Loans	Environmental Project Loan Amount /Total Loan Amount	Yu,B.,& Fan,C. (2022).
	Green Investment	Ratio of Environmental Pollution Control Investment to GDP	Environmental Pollution Control Investment / GDP.	Yan,Z. (2023)

	Green Insurance	Extent of Promotion of Environmental Pollution Liability Insurance	Environmental Pollution Liability Insurance Revenue / Total Premium Income	
	Green Bonds	Degree of Development of Green Bonds	Total Issued Green Bonds / Total Bond Issuance	
	Green Support	Ratio of Fiscal Environmental Protection Expenditure to General Budget Expenditure	Fiscal Environmental Protection Expenditure / General Budget Expenditure	Lin,M.,& Xiao,Y.(2023)
	Green Funds	Ratio of Green Fund Market Value to Total Fund Market Value	Total Market Value of Green Funds / Total Market Value of All Funds	Xue, H., & Kan, L. (2024)
	Carbon Finance	Carbon Emission Intensity	Carbon Emissions / GDP	

Control variables

This study selects variables with significant impacts on ecological welfare performance as control variables. Drawing from the research of Fang, S., & Xiao, Q. (2019), Guo, B., & Tang, L. (2023), Gu, D., & Chen, Y. (2020), and Zhao, L., Zhang, H., & Li, M. (2024), this study includes openness, innovation level, industrial structure, and environmental regulation as control variables.

Table3: Control Variables

Control Variable	Operational Definition	Notes
Degree of Openness	Foreign Direct Investment / GDP	Fang & Xiao (2019)
Level of Innovation	Number of Invention Patent Applications Accepted Annually	Guo & Tang (2023)
Industrial Structure	Value Added of the Tertiary Industry / Value Added of the Secondary Industry	Gu, D., & Chen, Y. (2020).
Environmental Regulation	Investment in Industrial Pollution Control / Industrial Value Added	Zhao, L., Zhang, H., & Li, M. (2024)

3.3 Data Sources and Descriptive Statistics

Data Sources

Considering the completeness and accessibility of data for each specific indicator, this study will collect data from 2000 to 2021 for 30 provincial-level administrative regions in China, excluding Tibet, Taiwan, Macau, and Hong Kong.

For the ecological welfare performance indicator system, the data sources are as follows: For resource input indicators, energy consumption data are obtained from the China Energy Statistical Yearbook, while data on land resource consumption and water resource consumption are sourced from the China Statistical Yearbook. The three indicators for economic development welfare are derived from the China Statistical Yearbook. Health welfare indicators are obtained from the China Health Statistical Yearbook and the China Population and Employment Statistical Yearbook. Data for three specific environmental welfare indicators are sourced from the China Statistical Yearbook.

For non-desired output indicators, the data are collected from the China Environmental Statistical Yearbook. In the green finance indicator system, data on green credit, green bonds, and green funds are sourced from the China Financial Statistical Yearbook, green investment data are obtained from the China Environmental Statistical Yearbook, green insurance data come from the China Insurance Yearbook, and green support data are derived from the China Statistical Yearbook. Carbon emissions data are acquired from the CEADs China Carbon Accounting Database.

For control variables, data on the degree of openness and industrial structure are obtained from the China Statistical Yearbook, environmental regulation data are sourced from the China Environmental Statistical Yearbook, and the level of innovation data are accessed through the China Research Data Service Platform (CNRDS).

Descriptive statistics

This study calculates the green finance index using the entropy weight method and the ecological welfare performance index using the super-efficiency SBM model with undesirable outputs. The development levels of ecological welfare performance in the eastern, central, western, and northeastern regions of China, as well as for China as a whole, from 2000 to 2021 are examined (see Table 4). Overall, ecological welfare performance in China decreased initially from 2000 until it reached its lowest point in 2006. Since 2006, it has exhibited a trend of gradual annual increases. Regionally, the eastern region has the highest average annual level of ecological welfare performance, followed by the central region, the western region, and the northeastern region, which is relatively weaker. There are noticeable differences in the development levels of ecological welfare performance among these regions.。

Table 4: Development level of ecological welfare performance

Year	Eastern region	Central region	Western region	Northeastern region	China
2000	0.533	0.668	0.511	0.292	0.528
2001	0.48	0.588	0.531	0.294	0.502
2002	0.533	0.483	0.53	0.291	0.498
2003	0.412	0.562	0.439	0.289	0.439
2004	0.404	0.475	0.397	0.288	0.404
2005	0.381	0.353	0.31	0.292	0.341
2006	0.369	0.316	0.248	0.272	0.304
2007	0.39	0.348	0.265	0.283	0.325
2008	0.404	0.374	0.315	0.287	0.354
2009	0.434	0.411	0.343	0.29	0.382
2010	0.448	0.39	0.287	0.3	0.363
2011	0.489	0.474	0.341	0.32	0.415
2012	0.562	0.49	0.374	0.335	0.456
2013	0.62	0.521	0.396	0.331	0.489
2014	0.746	0.539	0.398	0.345	0.537
2015	0.662	0.584	0.421	0.355	0.527
2016	0.694	0.57	0.466	0.35	0.551
2017	0.757	0.588	0.502	0.362	0.59
2018	0.769	0.591	0.58	0.379	0.625
2019	0.802	0.681	0.661	0.405	0.686
2020	0.797	0.702	0.73	0.494	0.723

2021	0.866	0.827	0.802	0.548	0.803
Annual average	0.5705	0.5244	0.4476	0.3364	0.4928

The development levels of green finance in the eastern, central, western, and northeastern regions of China, as well as in China as a whole, from 2000 to 2021 are examined (see Table 5). Overall, green finance has exhibited a trend of annual increases since 2000. Regionally, the northeastern region has the highest average annual level of green finance, followed by the western region, then the eastern region, with the central region having the lowest level of green finance development. There are noticeable differences in the development levels of green finance among these regions.

Table 5: Development level of green finance

Year	Eastern region	Central region	Western region	Northeastern region	China
2000	0.0967	0.0930	0.0921	0.1231	0.0969
2001	0.1256	0.1272	0.1329	0.1301	0.1291
2002	0.1640	0.1604	0.1771	0.1636	0.1681
2003	0.2003	0.2023	0.2062	0.2190	0.2047
2004	0.2389	0.2459	0.2476	0.2312	0.2427
2005	0.2750	0.2955	0.2610	0.3099	0.2775
2006	0.3228	0.3168	0.3134	0.3256	0.3184
2007	0.3538	0.3329	0.3500	0.3482	0.3477
2008	0.3897	0.3813	0.3913	0.4105	0.3907
2009	0.4180	0.4339	0.4369	0.4530	0.4316
2010	0.4662	0.4412	0.4447	0.4952	0.4562
2011	0.4847	0.4815	0.4875	0.4842	0.4851
2012	0.5157	0.5274	0.5433	0.5357	0.5302
2013	0.5583	0.5665	0.5809	0.5937	0.5718
2014	0.6079	0.5938	0.6126	0.6080	0.6068
2015	0.6129	0.6239	0.6203	0.6658	0.6231
2016	0.6824	0.6682	0.6773	0.6291	0.6723
2017	0.7077	0.6915	0.7177	0.7559	0.7130
2018	0.7661	0.7329	0.7529	0.7537	0.7534
2019	0.7873	0.7987	0.7861	0.7937	0.7898
2020	0.8173	0.8128	0.7914	0.7993	0.8051
2021	0.8610	0.8474	0.8488	0.8935	0.8571
总计	0.4751	0.4716	0.4760	0.4874	0.4760

4.Empirical analysis

4.1 Modeling prerequisite testing

For modeling panel data with time series components, it is generally required that the variables exhibit significant correlations, that the series for each variable are stationary, and that there is cointegration among the variables. These conditions will be verified in this study. To enhance the stationarity of the data series, this research first applies a logarithmic transformation to each variable before proceeding with the subsequent analysis.

Correlation test

Table 6 shows that the correlation coefficient between the dependent variable ecological welfare performance (lnstfl) and the explanatory variable green finance (lngreenf) is 0.250, which is significant at the 1% level. The correlation coefficients between ecological welfare performance and the control variables—environmental regulation (lnhjgz), industrial structure (lncyjg), innovation level (lncxsp), and openness (lndwkf)—are -0.321, 0.349, 0.595, and 0.110, respectively, all significant at the 1% level. These results indicate strong correlations among the variables, which forms the basis for constructing the econometric model.

Table 6: Pearson correlation test

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
（1）lnstfl	1.000					
（2）lngreenf	0.250	1.000				
（3）lnhjgz	-0.321	-0.416	1.000			
（4）lncyjg	0.349	0.342	-0.385	1.000		
（5）lncxsp	0.431	0.694	-0.520	0.316	1.000	
（6）lndwkf	0.110	-0.204	-0.151	-0.005	0.164	1.000

Stability test

The Fisher and LLC tests were used to examine the stationarity of each variable. The results indicate that the variables are non-stationary at their levels but become stationary after first differencing (see Table 7). This suggests that all variables exhibit significant first-order stationarity.

Table 7: Stationarity test

variable	**Test statistical indicators**			**Statistic**	**p-value**
D.lnstfl	Fisher	Inverse chi-squared(60)	P	354.4733	0.0000
		Inverse normal	Z	-11.0818	0.0000
		Inverse logit t(154)	L*	-16.9422	0.0000
		Modified inv. chi-squared	Pm	26.8816	0.0000
	Levin–Lin–Chu		Adjusted t*	-11.257	0.0000
D.lngreenf	Fisher	Inverse chi-squared(60)	P	639.4387	0.0000
		Inverse normal	Z	-21.2035	0.0000
		Inverse logit t(154)	L*	-32.2685	0.0000
		Modified inv. chi-squared	Pm	52.8953	0.0000
	Levin–Lin–Chu		Adjusted t*	-11.9977	0.0000
D.lnhjgz	Fisher	Inverse chi-squared(60)	P	263.745	0.0000
		Inverse normal	Z	-10.8419	0.0000
		Inverse logit t(154)	L*	-12.8764	0.0000
		Modified inv. chi-squared	Pm	18.5993	0.0000
	Levin–Lin–Chu		Adjusted t*	-2.8574	0.0021
D.lncyjg	Fisher	Inverse chi-squared(60)	P	131.5651	0.0000
		Inverse normal	Z	-5.297	0.0000
		Inverse logit t(154)	L*	-5.469	0.0000
		Modified inv. chi-squared	Pm	6.533	0.0000
	Levin–Lin–Chu		Adjusted t*	-4.9121	0.0000
D.lncxsp	Fisher	Inverse chi-squared(60)	P	194.709	0.0000
		Inverse normal	Z	-8.0048	0.0000
		Inverse logit t(154)	L*	-9.0504	0.0000

		Modified inv. chi-squared	Pm	12.2972	0.0000
	Levin–Lin–Chu		Adjusted t*	-6.3822	0.0000
D.lnczhsp	Fisher	Inverse chi-squared(60)	P	244.8391	0.0000
		Inverse normal	Z	-11.3688	0.0000
		Inverse logit t(154)	L*	-12.2605	0.0000
		Modified inv. chi-squared	Pm	16.8734	0.0000
	Levin–Lin–Chu		Adjusted t*	-10.3246	0.0000
D.lndwkf	Fisher	Inverse chi-squared(60)	P	245.8863	0.0000
		Inverse normal	Z	-9.285	0.0000
		Inverse logit t(154)	L*	-11.3392	0.0000
		Modified inv. chi-squared	Pm	16.969	0.0000
	Levin–Lin–Chu		Adjusted t*	-7.5173	0.0000

Cointegration test

First, the lag order of cointegration for the variables ecological welfare performance, green finance, environmental regulation, industrial structure, innovation level, and openness was determined based on information criteria. The output indicates that, according to the information criteria MBIC, MAIC, HQIC, and SBIC, the lag order of cointegration among the variables is one.

Table 8: Order of cointegration among the variables

lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	1.000	242.263	0.014	-967.799*	-149.737*	-471.299*
2	1.000	175.038	0.057	-732.509	-118.962	-360.134
3	1.000	117.635	0.086	-487.396	-78.365	-239.147
4	1.000	54.335	0.279	-248.181	-43.665	-124.056

*Represents the minimum value

To further investigate the cointegration among the variables, both Pedroni and Kao tests were conducted. The results reveal the presence of cointegration among the variables, indicating that there is a long-term equilibrium relationship among them.

Table 9: Pedroni and Kao cointegration test

Statistics of the cointegration test		Statistic	p-value
Pedroni	Modified Phillips–Perron t	5.3872	0.0000
	Phillips–Perron t	-3.3919	0.0003
	Augmented Dickey–Fuller t	-2.8954	0.0019
Kao	Modified Dickey–Fuller t	-3.1627	0.0008
	Dickey–Fuller t	-4.1051	0.0000
	Augmented Dickey–Fuller t	-2.317	0.0103
	Unadjusted modified Dickey–Fuller t	-7.3287	0.0000
	Unadjusted Dickey–Fuller t	-5.9265	0.0000

In summary, the variables—ecological welfare performance, green finance, environmental regulation, industrial structure, innovation level, and openness—exhibit first-order stationarity. Additionally, there are significant correlations among these variables, and they demonstrate notable first-order cointegration. These findings provide a foundation for the construction and analysis of econometric regression models.

4.2 Data Analysis

Threshold Regression Analysis

Firstly, a triple threshold regression model was established with ecological welfare performance as the dependent variable and green finance as the threshold variable. The threshold effect of green finance was then tested. The results indicate that, at the 5% confidence level, the dual threshold effect is significant. Further calculations reveal that the threshold values under the dual threshold regression model are -1.2571 and -1.7284,Firstly, a triple threshold regression model was established with ecological welfare performance as the dependent variable and green finance as the threshold variable. The threshold effect of green finance was then tested. The results indicate that, at the 5% confidence level, the dual threshold effect is significant. Further calculations reveal that the threshold values under the dual threshold regression model are -1.2571 and -1.7284.

Table 10:Self-sampling test results of the threshold effect of green Finance

Threshold	RSS	MSE	Fstat	Prob	Crit10	Crit5	Crit1
Single	72.165	0.1131	48.66	0.0000	19.5601	23.5773	33.3053
Double	68.4803	0.1073	34.33	0.0000	18.9718	22.3357	24.1941
Triple	67.1816	0.1053	12.33	0.3400	19.4674	23.6366	35.4199

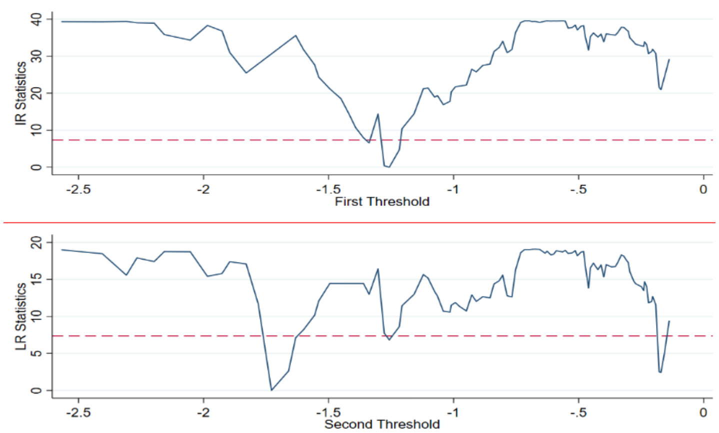

Figure 1:Estimate of the green Finance threshold

The results in Table 11 indicate that as the level of green finance increases, its nonlinear impact on ecological welfare performance becomes increasingly pronounced. Specifically, when green finance is below -1.7284, its effect on ecological welfare performance is minimal and not significant. However, when green finance ranges from -1.7284 to -1.2571, the impact coefficient on ecological welfare performance increases to 0.157, which is significant at the 10% level. Furthermore, when green finance exceeds -1.2571, the impact coefficient on ecological welfare performance further increases to 0.431, and this effect is significant at the 1% level.

Table 11: Estimation of the regression coefficient of the green finance threshold

	Coefficient	Std. err.	t	P>t
Lngreenf<-1.7284	-0.063	0.071	-0.890	0.372
-1.728<lngreenf<-1.257	0.157*	0.090	1.730	0.083
Lngreenf>-1.257	0.431***	0.111	3.900	0.000

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In summary, there is a significant threshold effect in the impact of green finance on ecological welfare performance. The higher the level of green finance development, the stronger its positive effect on ecological welfare performance, displaying notable nonlinear characteristics. Based on these findings, this study will further develop a panel regression model to specifically characterize the nature of this nonlinear impact.

Baseline regression analysis

In this study, the square term of green finance (lngreenf) is introduced into the regression models to specifically examine the nonlinear impact of green finance on ecological welfare performance. Several regression models are constructed, with green finance as the explanatory variable and ecological welfare performance as the dependent variable. Model a1 represents a mixed regression model without control variables, while model a2 includes control variables. Model a3 is a panel random effects regression model without control variables, and model a4 includes control variables. Model a5 is a panel fixed effects regression model without control variables, and model a6 includes control variables.

The results indicate that, across models a1 through a6, green finance has a significant positive effect on ecological welfare performance at the 1% significance level, with a pronounced nonlinear effect also observed. This confirms the robustness of the conclusion regarding the positive nonlinear impact of green finance on ecological welfare performance. The specific form of the nonlinear impact is a positive U-shape.

Table 12:Baseline regression model Estimation

	Mixed regression models		**Random-effects panel regression model**		**Fixed-effects panel regression model**	
	(a1)	(a2)	(a3)	(a4)	(a5)	(a6)
lngreenf	1.3781***	0.8927***	1.3755***	0.5575***	1.3754***	0.5838***
	(12.6194)	(6.6650)	(17.5043)	(3.7668)	(17.4823)	(3.4058)
lngreenf2	0.4886***	0.3848***	0.4861***	0.2932***	0.4860***	0.2964***
	(10.9941)	(8.1330)	(15.1888)	(6.7501)	(15.1670)	(6.2902)
lnhjgz		-0.0193		-0.0614***		-0.0605***
		(-0.7569)		(-2.7674)		(-2.6694)
lncyjg		0.1833***		0.2568***		0.2484***
		(3.3642)		(3.5297)		(3.0936)
lncxsp		0.7850***		0.9377***		0.8491***
		(6.3370)		(4.5981)		(3.3602)
lndwkf		0.0436**		-0.0713***		-0.0904***
		(2.2876)		(-3.2802)		(-3.8485)
_cons	-0.1990***	-2.0854***	-0.1983***	-3.3213***	-0.1983***	-3.1901***
	1.3781***	0.8927***	1.3755***	0.5575***	1.3754***	0.5838***
N	660	660	660	660	660	660
adj. R2	0.208	0.313			0.348	0.361

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Further, the Hausman test is conducted for both the random effects model and the fixed effects model. The test results show that chi2(7) = 10.77 and Prob > chi2 = 0.1487, with a p-value greater than 0.05, indicating that there is no significant difference between the coefficients of the random effects model and the fixed effects model. Therefore, the random effects model is more efficient than the fixed effects model. Based on this, the study selects model a4 to describe the nonlinear impact of green finance on ecological welfare performance.

According to this model, the impact of green finance on ecological welfare performance shows a significant U-shaped nonlinear relationship: the coefficient for green finance is 0.5575, while the coefficient for the square term of green finance is -0.2932. This implies that as the level of green finance increases, it increasingly promotes the enhancement of ecological welfare performance.

It is also observed that, under the consideration of the U-shaped nonlinear effect of green finance, each control variable has a significant impact on ecological welfare performance: specifically, the industrial structure and innovation level have positive effects, with coefficients of 0.2568 and 0.9377, respectively. This indicates that a higher proportion of the tertiary industry and a higher level of technological innovation can better promote the improvement of ecological welfare performance. On the other hand, environmental regulation has a negative impact on ecological welfare performance, with a coefficient of -0.0614. This negative effect might be due to increased economic costs during the implementation of environmental regulations, insufficient policy enforcement, and inadequate corporate adaptability. Additionally, openness to foreign trade also exhibits a negative effect, with a coefficient of -0.0713. This phenomenon may arise from the fact that foreign direct investment prioritizes commercial economic benefits over environmental and social welfare concerns, leading to environmental degradation, regulatory challenges, and socio-economic inequalities.

Endogeneity and Robustness Analysis

Based on the system GMM dynamic panel model, with ecological welfare performance as the dependent variable and the one-period lagged term of ecological welfare performance as an instrumental variable, green finance is used as the explanatory variable. The model is fitted using a two-stage approach to establish model b1. Next, a squared term of green finance is added to model b1 to examine the nonlinear spatial convergence effect of green finance on ecological welfare performance, resulting in model b2. Finally, control variables are included to assess their impact on ecological welfare performance under the nonlinear influence of green finance, leading to model b3. The fitting results of each model are presented in Table 13.

The regression results of model b1 indicate that the coefficient for green finance is 0.3231 and is significant at the 1% level, suggesting a significant positive impact of green finance on ecological welfare performance, consistent with the previous conclusions. The results of model b2 show that the coefficient for the squared term of green finance is 0.4757 and is significant at the 1% level, indicating a significant positive U-shaped nonlinear effect of green finance on ecological welfare performance, which aligns with the previous conclusions. The results of model b3, which includes control variables, reveal that the nonlinear positive U-shaped effect of green finance and its squared term on ecological welfare performance remains significant, confirming the robustness of the conclusion that green finance has a positive U-shaped nonlinear impact on ecological welfare performance.

Table 13:Two-stage systematic GMM model estimation

	(b1)	**(b2)**	**(b3)**
L.lnstfl	0.4947***	0.2451***	0.2099***
	(58.9426)	(14.8487)	(8.5571)
lngreenf	0.3231***	1.3754***	0.6336***
	(28.1490)	(22.6207)	(6.8200)
lngreenf2		0.4757***	0.3418***
		(19.7077)	(10.1799)
lnhjgz			-0.0424***
			(-9.7968)
lncyjg			0.0367
			(0.8952)
lncxsp			1.4648***
			(14.7846)
lndwkf			-0.0628***
			(-7.3415)
_cons	-0.1352***	0.0631***	-4.0764***

	(-7.8351)	(2.8299)	(-17.5236)
Wald	4049.87	4201.04	4268.63
Prob > chi2	0.000	0.000	0.000

The Sargan test was employed to examine the validity of over-identification in the three models. The results (see Table 14) show that the p-values of the Sargan statistics for these models are 1.0000, which is well above the 0.05 significance level. This indicates that the instrumental variables used in these models are valid and appropriate, with no over-identification issues and no significant endogeneity.

Furthermore, the Arellano-Bond test for autocorrelation was conducted. If first-order autocorrelation is significant and second-order autocorrelation is not significant, it suggests that the model is correctly specified and effectively captures the dynamic features of the dependent variable, indicating that the model estimates are valid and robust. Conversely, if both first-order and second-order autocorrelation are significant, it implies that the model may be missing important variables, leading to potential estimation bias and reduced validity of the model.

The test results (see Table 14) reveal that for model b1, when examining the impact of green finance on ecological welfare performance alone, the Arellano-Bond test shows that the significance level of second-order autocorrelation is 0.03 < 0.05, indicating possible model misspecification due to omitted variables, leading to estimation bias and reduced model validity. However, when the squared term of green finance is added to model b1, the second-order autocorrelation becomes non-significant (with a significance level of 0.0638, greater than 0.05), indicating that the model estimates become valid and robust. Both model b2 and model b3, which include the squared term of green finance, also show robust Arellano-Bond test results. This suggests that when examining the impact of green finance on ecological welfare performance, it is essential to consider the nonlinear effects of green finance, further confirming the significant nonlinear impact of green finance on ecological welfare performance.

In summary, based on the results from the threshold regression analysis, mixed regression analysis, benchmark regression analysis, and the Arellano-Bond and Sargan tests, all findings converge on a consistent result: green finance has a nonlinear effect on ecological welfare performance and its spatial convergence, and this conclusion is robust.

Table 14:Arellano-Bond and Sargan tests of the systematic GMM model

	Arellano–Bond test			**Sargan test**	
	Order	**z**	**Prob > z**	**chi2(230)**	**Prob > chi2**
Model（b1）	1	-2.6094	0.0091	27.97363	1
	2	2.1704	0.0300		
Model（b2）	1	-2.5437	0.0110	27.44862	1
	2	1.8537	0.0638		
Model（b3）	1	-2.4496	0.0143	28.49348	1
	2	1.8324	0.0669		

Heterogeneity Analysis

According to the classification standards for geographic location and economic development level by the National Bureau of Statistics of China, the sample period is divided into four regions: Eastern, Central, Western, and Northeastern China. The nonlinear impact of green finance on ecological welfare performance across these regions is examined. The results of the regression analysis are presented in Table 15. The findings indicate that while green finance has a significant positive nonlinear effect on ecological welfare performance in all regions, the magnitude of this effect varies across different regions. Additionally, the impact of control variables on ecological performance also shows regional differences. This suggests that the positive nonlinear impact of green finance on ecological welfare performance exhibits regional heterogeneity.

Table 15:Regression estimates of heterogeneity tests

	D1	**D2**	**D3**	**D4**	**D5**
	Eastern region	**Central region**	**Western region**	**Northeastern region**	**China**
lngreenf	0.9679***	1.9885***	0.6409**	0.4116**	0.5575***
	(7.1396)	(4.5281)	(2.2101)	(2.0158)	(3.7668)
lngreenf2	0.4249***	0.6471***	0.2791***	0.2413***	0.2932***
	(9.3796)	(4.6846)	(3.2293)	(3.9243)	(6.7501)
lnhjgz	0.0062	-0.0091	-0.0941*	-0.0516**	-0.0614***
	(0.2741)	(-0.1192)	(-1.8445)	(-2.0344)	(-2.7674)
lncyjg	0.2200***	-0.1604	0.3999**	-0.1501**	0.2568***
	(4.2286)	(-0.7313)	(2.2517)	(-2.4091)	(3.5297)
lncxsp	1.3902***	-0.6089	0.2674	1.5097***	0.9377***
	(9.7882)	(-1.0101)	(0.7294)	(4.1921)	(4.5981)
lndwkf	0.1253***	-0.3051***	-0.0835**	-0.0676**	-0.0713***
	(3.2066)	(-3.3791)	(-2.1596)	(-2.2526)	(-3.2802)
_cons	-2.9280***	0.2104	-2.1844**	-4.8147***	-3.3213***
	(-7.2454)	(0.1220)	(-2.3977)	(-4.9526)	(-6.1773)

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Expandability Analysis

As observed from the baseline regression analysis, environmental regulation, openness, innovation level, and industrial upgrading all exhibit significant impacts on ecological welfare performance when considering the influence of green finance. To further investigate the nonlinear mechanisms of green finance within the context of these control variables' effects on ecological welfare, a threshold regression model with green finance as the threshold variable is employed. The results of the threshold effect from the sample test are shown in Table 16.

The output indicates that green finance exhibits a threshold effect in the context of industrial upgrading's impact on ecological welfare performance. Moreover, significant dual threshold effects of green finance are observed in the contexts of environmental regulation, openness, and innovation level affecting ecological welfare performance. The first and second threshold values are consistently -1.7284 and -1.2775, respectively. Notably, the dual threshold effect of green finance on ecological welfare performance is observed with a first threshold value of -1.2784 and a second threshold value of -1.2571, which is close to -1.2775. This proximity suggests a degree of robustness in the threshold values for the nonlinear effects of green finance.

Table 16:Self-sampling tests for the threshold effects of the control variables

	Threshold	**RSS**	**MSE**	**Fstat**	**Prob**	**Crit10**	**Crit5**	**Crit1**
Environmental regulation	Single	73.1168	0.1146	90.81	0.000	40.6284	45.3821	57.2301
	Double	70.0473	0.1098	27.96	0.040	20.2734	23.5328	30.7525
Openness level	Single	73.1168	0.1146	90.81	0.000	40.6284	45.3821	57.2301
	Double	70.0473	0.1098	27.96	0.040	20.2734	23.5328	30.7525

Innovation level	Single	72.6595	0.1139	95.4	0.000	36.3749	44.4903	56.6788
	Double	70.1272	0.1099	23.04	0.0733	21.333	26.9207	33.1413

Dual threshold regression models are established with green finance as the threshold variable to examine its impact on ecological welfare performance, specifically in the contexts of environmental regulation, openness, and innovation level. The regression results are presented in Table 17.

The results in column c1 reveal that as the level of green finance increases, the negative constraint effect of environmental regulation on ecological welfare performance progressively diminishes. When green finance is below -1.7284, the negative impact of environmental regulation on ecological welfare performance is at its highest, with a coefficient of -0.1918, significant at the 1% level. When -1.728 < green finance < -1.2775, the negative impact of environmental regulation decreases to -0.1093, still significant at the 1% level. When green finance exceeds -1.2775, the negative impact of environmental regulation further diminishes to -0.0593, significant at the 1% level.

The results in column c2 indicate that as the level of green finance rises, the negative constraint effect of openness on ecological welfare performance also weakens. When green finance is below -1.7284, the negative impact of openness on ecological welfare performance is at its maximum, with a coefficient of -0.2055, significant at the 1% level. When -1.728 < green finance < -1.2775, the negative impact of openness decreases to -0.1112, significant at the 1% level. When green finance exceeds -1.2775, the negative impact of openness further reduces to -0.04527, significant at the 5% level.

The results in column c3 demonstrate that as the level of green finance increases, the positive promotion effect of innovation level on ecological welfare performance also declines. When green finance is below -1.7284, the positive impact of innovation level on ecological welfare performance is at its peak, with a coefficient of 1.7740, significant at the 1% level. When -1.728 < green finance < -1.2775, the positive impact of innovation level decreases to 1.5466, significant at the 1% level. When green finance exceeds -1.2775, the positive impact of innovation level further weakens to 1.4215, significant at the 5% level.

Table 17:Threshold regression estimates of t control variables on EWP

	C1	**C2**	**C3**
	Environmental regulation	**Openness level**	**Innovation level**
Lngreenf<-1.7284	-0.1918*** （-8.11）	-0.2055*** （-8.27）	1.7740*** （10.73）
-1.728<lngreenf<-1.2775	-0.1093*** （-4.84）	-0.1112*** （-4.56）	1.5466*** （9.84）
Lngreenf>-1.2775	-0.0593*** （-2.8）	-0.04527** （-1.91）	1.4215*** （10.10）

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In summary, with the exception of industrial structure, green finance exerts a significant dual-threshold nonlinear impact on the effects of environmental regulation, openness, and innovation level on ecological welfare performance. Specifically, green finance mitigates the negative impact of environmental regulation and openness on ecological welfare performance, though this mitigating effect diminishes as the level of green finance increases. Conversely, green finance enhances the positive impact of innovation level on ecological welfare performance, yet this enhancement wanes as the level of green finance rises.

5. RESEARCH FINDINGS AND RECOMMENDATIONS

5.1 Research Findings

This study examines the nonlinear impact of green finance on ecological welfare performance, providing a novel perspective for researching the relationship between green finance and ecological welfare performance. Utilizing provincial panel data from 2000 to 2021, the study employs the entropy weight method and the non-desired output super-efficiency SBM model to measure the levels of green finance development and ecological welfare performance. Based on this, threshold regression models and benchmark regression models are established to explore the nonlinear impact of green finance on ecological welfare performance, with the two-stage system GMM dynamic regression model used to verify the robustness of the findings.

The research reveals that green finance itself has a significant dual-threshold nonlinear impact on ecological welfare performance. Specifically, as the level of green finance increases, its positive impact on ecological welfare performance grows, following a U-shaped nonlinear pattern. Under the influence of green finance, industrial structure significantly promotes ecological welfare performance, with no evident threshold effect from green finance. Innovation level also positively impacts ecological welfare performance, but green finance introduces a notable dual-threshold effect in this relationship. As green finance levels rise, its positive effect on ecological welfare performance diminishes, indicating that while green finance enhances the positive impact of innovation level, this enhancement decreases over time.

Furthermore, considering the impact of green finance, environmental regulation and openness currently have significant negative effects on ecological welfare performance. Green finance exhibits a notable dual-threshold effect in this context, with the negative impacts of environmental regulation and openness on ecological welfare performance decreasing as green finance levels increase. This suggests that green finance development has a suppressive effect on the negative impacts of environmental regulation and openness.

In summary, green finance not only exhibits significant nonlinear effects on ecological welfare performance but also plays a nonlinear role in the influence of environmental regulation, openness, and innovation level on ecological welfare performance.

From a regional perspective, there are differences in the development levels of green finance and ecological welfare performance across different regions. Despite the positive U-shaped nonlinear effect of green finance on ecological welfare performance in the Eastern, Central, Western, and Northeastern regions, the degree of this nonlinear effect varies among regions. Additionally, the influence of control variables on ecological welfare performance also varies across regions when considering the impact of green finance. Thus, the impact of green finance on ecological welfare performance exhibits regional heterogeneity.

5.2 Recommendations

Based on the findings regarding the nonlinear impact of green finance on ecological welfare performance, several policy recommendations are proposed to optimize the development of green finance and enhance its positive effects on ecological welfare.

The positive U-shaped dual-threshold effect observed suggests that different stages of development require tailored policy support. In the early stages, the government should focus on promoting green finance through fiscal incentives and tax benefits, particularly for small and medium-sized environmental protection enterprises. As green finance progresses to the intermediate stage, it is crucial to improve transparency and regulation within financial markets to ensure that funds are directed towards green projects and to encourage innovation in green financial products. When green finance reaches an advanced level of development, attention should shift to addressing the diminishing marginal returns by concentrating support on high-quality green projects.

The impact of green finance varies significantly across different regions. For the Eastern region, there is a need to accelerate the internationalization of green finance, attract international capital, and innovate green financial instruments. In the Central region, financial policies should support industrial structure upgrading and promote green transformation. Meanwhile, in the Western and Northeastern regions, it is essential to enhance green finance infrastructure and increase the flow of financial resources into environmental governance projects.

Moreover, given the significant positive impact of industrial structure and innovation levels on ecological welfare performance, policies should further drive industrial structure optimization and encourage financial institutions to provide greater support for green technologies and clean energy. The role of green finance in innovation demonstrates diminishing marginal returns, making it important to focus on precise investments in green technological innovation to prevent inefficient resource allocation.

Finally, the negative impacts of environmental regulation and openness on ecological welfare performance can be mitigated through the regulatory role of green finance. Policymakers should consider introducing market-based mechanisms, such as carbon emission trading schemes, to enhance the flexibility of environmental regulations. Additionally, in terms of openness, strengthening international cooperation in green finance and aligning domestic green finance standards with international practices will be crucial.

These recommendations aim to foster a more effective and regionally adapted approach to green finance, ensuring that its development contributes positively to ecological welfare performance.

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