Research on the Impact of Green Finance on Ecological and Environmental Pollution Management in the Yangtze River Basin

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Abstract

As a key region in China's pollution prevention and control, the Yangtze River Basin, green finance is of great significance in promoting its green economic transformation process. Based on the panel data of 42 prefecture-level cities in the Yangtze River basin, this study constructs the green finance influence mechanism and transmission path after measuring the level of green finance development, in-depth analysis and empirical testing of the two-way fixed effect model and the mediated effect model for ecological and environmental pollution governance in the Yangtze River basin. The results of the benchmark regression show that green finance development can significantly enhance the level of ecological environment pollution governance in the basin; the mediating effect test shows that green finance plays an indirect effect through incentivizing innovation, which significantly enhances the technological content and practical effect of ecological environment pollution governance; the heterogeneity test finds that there are obvious regional differences in the impact of green finance on ecological environment pollution governance in the Yangtze River Basin. Based on the above conclusions, policy suggestions to promote the development of green finance in the Yangtze River Basin are proposed.

Keywords

Green Finance, Ecological Environment Pollution Governance, Innovation Level, Yangtze River Basin.

1. Introduction

As the cradle of Chinese civilization, the Yangtze River has provided key support for the progress of the Chinese nation. However, along with rapid economic growth, ecological problems in the basin have become increasingly prominent. Studies have shown that the natural shoreline has suffered large-scale destruction and crowding [1], wetlands show serious fragmentation characteristics, and the self-purification capacity and ecological service function of the water body continue to decline [2]. Research shows [3] that there is significant resource competition among metropolitan areas in the region, which not only causes deterioration of water bodies and atmospheric quality, but also triggers a series of ecological crises. At the same time, the upstream and downstream regions have failed to effectively coordinate their ecological development strategies [4], resulting in fragmented environmental protection efforts and the inability to form synergistic effects, which ultimately restricts the enhancement of the overall level of environmental governance.

Green finance, as a new model that integrates environmental protection concepts with traditional finance, plays a key role in connecting financial services and environmental industries. This kind of financial innovation has run the low-carbon concept through all aspects of financial operations, providing important support for the development of environmental industries. According to the research results of Ma et al [5], green finance has a significant role

in promoting environmental pollution management in the Yangtze River Basin. In the face of the increasingly severe ecological and environmental problems in the Yangtze River Basin, academics are focusing on whether green finance can play a positive role in environmental governance in the region.

Although the existing literature has explored the association between green finance and environmental pollution governance, its research scope is mainly limited to the whole country or other economic zones, and lacks a systematic analysis of the Yangtze River Basin, a special economic and geographical unit. Based on this, this paper takes the Yangtze River Basin as the research object and utilizes dynamic panel regression modeling to deeply explore the role mechanism of green finance in environmental governance in the region. When analyzing the regional impact of green finance on ecological governance, emphasis should be placed on examining the differences in economic development and environmental protection pressure in each region. By deeply exploring the operation mechanism of green finance under different levels of development, it can provide theoretical support for the formulation of precise regional policies.

2. Theoretical Analysis and Research Hypothesis

As a key financial instrument to promote ecological optimization, mitigate climate crisis, and promote efficient use of resources, green finance promotes the transformation of high-pollution and high-energy-consumption industries to environmental protection by optimizing resource allocation, thus enhancing the regional environment [6]. Relying on the market operation mode, environmental protection investment and financing can not only directly fund ecological projects, but also promote enterprise technological innovation through a combination of incentives and constraints [7], providing solid financial support for global environmental governance. Through this mechanism, environmental finance can guide capital toward ecological industries and projects, thus improving pollution management in the Yangtze River Basin. Based on this, this study proposes the following hypotheses:

H1:The level of environmental governance in the Yangtze River Basin has been significantly improved by the advancement of green finance.

The key driving force for the modernization of ecological governance capacity comes from scientific and technological progress [8]. Research has confirmed that the continuous breakthroughs in scientific and technological innovation have given rise to a large number of technological achievements, which have been deeply applied in the green financial system, not only accelerating the innovation process in this field, but also significantly improving the comprehensive benefits of the ecological economy [9]. Scientific and technological innovation has been significantly enhanced under the impetus of green finance [10], which not only strengthens the capacity of technological research and development, but also provides a solid guarantee for ecological governance. Facing the complex environmental problems in the Yangtze River Basin, such as serious soil erosion, lake siltation and resource depletion, the governance work faces high difficulty and high cost. However, through the application of scientific and technological innovations, pollution management in the region has been able to achieve more precise and efficient treatment [11]. Based on this, the following hypotheses are proposed in this study:

H2:Science and technology innovation helps environmental protection in the Yangtze River Basin, and green finance promotes governance effectiveness.

Huang [12] points out that the Yangtze River region shows significant differences in environmental protection governance needs and green finance effectiveness due to the characteristics of each province (region) in terms of economic level, industrial composition and resource conditions. In economically prosperous regions, the well-developed financial system,

deeply rooted concept of ecological protection, and sufficient experience in environmental management enable these regions to rapidly adopt and implement green financial strategies [13]. These regions are more inclined to utilize financial instruments such as green loans and environmental protection bonds to effectively attract environmental protection investment and promote the application of environmental protection technology, thus achieving significant environmental management effects. In contrast, regions with more lagging economic development in the basin encounter many obstacles in promoting and applying green finance, including difficulties in financing and insufficient environmental awareness. These factors make it difficult to fully realize the effects of green finance policies. In fact, these regions often face more serious ecological problems [14], and are constrained by factors such as insufficient local financial support and small business coverage of financial institutions, so that even if there are policy-oriented green financial tools, such as loan preferences or special funds, it is difficult to fully meet the needs of ecological environment management. This leads to the following hypothesis:

H3: There is regional heterogeneity in the impact of green finance development on ecological and environmental pollution management in the Yangtze River Basin.

3. Measurement of Green Finance Development Level in Yangtze River Basin

3.1. Entropy Value Method

Taking prefecture-level cities in the Yangtze River Basin as the sample unit, the entropy value method is used to measure the level of green financial development in the Yangtze River Basin.

1) Data standardization to minimize the impact of data variability on the measurements, positive indicators:

$$\mu_{ijt} = \frac{X_{ijt} - X_{minj}}{X_{miaxj} - X_{minj}} + 0.01$$

Negative indicators:

$\mu_{ijt} = \frac{X_{miaxj} - X_{itj}}{X_{miaxj} - X_{minj}} + 0.01$

Where: X_{ijt} is the value of the indicator j ($j = 1,2,\dots,n$) for the city i ($i = 1,2,\dots,m$) in the year t, X_{miaxj} is the maximum value of the indicator j, X_{minj} is the minimum value of the indicator j, μ_{ijt} is the standardized value of the indicator j for the city i in the year t.

2) Calculate the share of the city's i indicator j in year t s_{itj} :

$$s_{itj} = \frac{\mu_{ijt}}{\sum_{i=1}^{m} \mu_{ijt}}$$

3) Calculate the information entropy of the indicator j e_{jt} :

$$e_{jt} = -\frac{1}{\ln m} \sum_{i=1}^{m} s_{itj} \ln s_{itj}$$

4) Determine the combined weights of the indicators j w_{jt} :

$$w_{jt} = \frac{g_{jt}}{\sum_{j=1}^{n} g_{jt}}$$

Where:g_{jt} =1-e_{jt} , is the redundancy of information entropy.

5) Calculate the composite scoreA_{it} :

$$A_{it} = \sum_{j=1}^{n} \mu_{ijt} w_{jt}$$

3.2. Selection of Indicators

Drawing on existing literature, a green financial development evaluation index system is constructed based on green investment, green securities, green credit, and green insurance, as shown in Table 1.Green investment reflects the government's investment in environmental protection [15], and is measured by using the proportion of investment in environmental pollution control to GDP. Green securities mainly reflect the ability of listed enterprises to raise funds by issuing securities [16], which is mainly measured by the share of market capitalization of environmental protection enterprises. Green credit reflects the credit support of financial institutions for environmental protection projects, which is measured by the ratio of total credit for environmental protection projects to total credit [5], and is measured by the credit share of environmental protection projects. Green insurance reflects the promotion of environmental pollution liability insurance, which is measured by the proportion of environmental pollution liability insurance revenue to total premium revenue, indicating the penetration of green insurance in the whole insurance market [5].

Table 1. Evaluation system of green financial development indicators

norm	Meaning of the indicator	Calculation of indicators	Indicator properties
green investment	Investment in environmental pollution control as a share of GDP	Investment in environmental pollution control/GDP	forward
Green Securities	Market capitalization share of environmental protection companies	Market capitalization of environmental protection companies/Total A-share market capitalization	forward
green credit	Percentage of credits for environmental projects	Total credit/total credit for environmental projects	forward
green insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income/total premium income	forward

4. Empirical Analysis of the Impact of Green Finance on Ecological Environment Pollution Management

4.1. Variable Selection and Data Sources

4.1.1. Selection of Variables

1) Explained variables. The level of ecological environment pollution management is the explanatory variable. According to the existing literature, industrial pollution is the main source of ecological environment pollution in China [17], the ratio between reasonable industrial sulfur dioxide emissions and the amount of production, the ratio between reasonable industrial wastewater emissions and the amount of production, the ratio between reasonable industrial solid waste emissions and the amount of production are selected as the evaluation indexes and the entropy method is used to measure the level of ecological environment pollution governance.

2) Explanatory variables. Green finance is the explanatory variable. The level of green financial development is the core indicator for measuring the comprehensive strength of green finance, and the green financial development evaluation index constructed based on Table 1 adopts the entropy value method to calculate the level of green financial development.

3) Control variables. The level of economic development, urban population density, and foreign direct investment were selected as control variables. Per capita GDP is an important indicator of the level of regional economic development [18], which has an important impact on ecological environmental governance, and taking per capita GDP as a control variable helps to exclude the interference of economic factors on the research results. Urban population density reflects the ecological carrying capacity of the region [19], and taking urban population density as a control variable helps to exclude the interference of the research results. Strict foreign direct investment can effectively limit the pollution emission of enterprises, promote clean production and improve environmental protection investment, the intensity of foreign direct investment as a control variable, foreign direct investment also affects the economic development and ecological environment of the country of the investment object [20], the use of foreign direct investment amount of the proportion of GDP to measure foreign direct investment.

4) Mediating variable. The level of innovation serves as a mediating variable. The level of innovation is a comprehensive indicator reflecting a region's technological research and development, innovation capacity and technology application and promotion. It is measured by taking the logarithm of the number of domestic invention patent applications received.

4.1.2. Data Sources

The Yangtze River flows through eleven provinces, namely Qinghai, Tibet, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Shanghai, with about 42 prefecture-level cities directly flowing through it. Based on the accessibility, continuity and scientificity of the data, and with reference to the geographic location characteristics of the cities in the Yangtze River Basin, Yichang in Hubei Province and Hukou in Jiangxi Province are taken as the demarcation points of the upper, middle and lower reaches of the Yangtze River. The data on environmental pollution, energy, population, economic and social development, etc. are obtained from the websites of the National Bureau of Statistics, the Ministry of Science and Technology, and the People's Bank of China, as well as from the national and provincial statistical yearbooks and environmental situation bulletins. The study period is from 2012 to 2022, and the data are based on the actual data of that year. The basic data involved are processed and analyzed by preliminary statistics, unit conversion, formula calculation, merging and summarizing. The statistical descriptions of various variables are shown in Table 2.

Table 2. Statistical description of various variables

variable name	notation	unit (of measure)	average value	(statistics) standard deviation	minimum value	maximum values	sample size
Level of ecological pollution control	P		0.7163	0.7512	-1.7877	1.7219	1139
Level of green finance development	G		0.0007	6.3081	11.2577	21.3116	1139
GDP per capita	S_{GDP}	¥	12121.790	729.013	6576.09	41439.86	1139
Urban population density	S_D		594.954	82.631	2.182	3925.868	1139
overseas foreign direct investment (OFDI)	S_E	%	0.198	0.0205	0.0154	1.5476	1139
Innovation level	S_T		0.8239	0.01806	0.1169	0.996124	1139

4.2. Conclusion and Discussion

4.2.1. Baseline Regression Results

To test hypothesis H1, a two-way fixed-effects model is constructed to study the impact of green financial development on the level of ecological and environmental pollution control in the Yangtze River Basin, and the model is set:

$$P_{it} = \alpha_0 + \alpha_1 G_{it} + \alpha_2 C_{it} + \theta_{it} + \beta_{it} + \varepsilon_{it} \quad (1)$$

Where:P_{it} andG_{it} are the level of ecological environment pollution control (smaller value ofP_{it} means lower level) and the level of green finance development of the cityi in the yeart ,C_{it} is the control variable,α_0 is the constant term,α_1 andα_2 are the regression coefficients of the green finance development and the control variables affecting the ecological environment pollution control,θ_{it} is the fixed effect of time (year),β_{it} is the fixed effect of the city, andε_{it} is the random perturbation term.

The results of the benchmark regression are shown in Table 3, and it can be seen that the impact of green finance on ecological and environmental pollution governance in the Yangtze River Basin is significant regardless of whether control variables are added or not, and that the development of green finance has a significant role in promoting ecological and environmental pollution governance in the Yangtze River Basin. The reason for this is that green finance can promote investment in environmentally friendly projects, thus reducing pollutant emissions, and at the same time, the introduction of green financial tools, such as green insurance and green credit, helps to guide the flow of funds to environmental protection technologies, such as clean energy and low-carbon technology, and enhance the level of regional ecological and environmental pollution governance. From the perspective of control variables, the regression coefficient of GDP per capita is positive, indicating that regions with higher levels of economic development invest more resources in environmental protection infrastructure construction and technological innovation, which helps to improve the level of ecological and environmental pollution management. The coefficient of urban population density is also positive, indicating

that the higher the provincial and municipal population density of the region, the stronger the awareness of environmental protection, which is favorable to the management of ecological and environmental pollution. The regression coefficient of foreign direct investment intensity is positive, indicating that foreign direct investment can effectively inhibit ecological environment pollution and improve regional ecological environment quality.

Table 3. Benchmark regression results

variant	regression coefficient	
	No control variables added	Adding Control Variables
G	0.1144** (2.01)	0.1585*(1.98)
S_{GDP}		0.0003** (2.21)
S_D		-0.0010** (-2.38)
S_E		-11.8637*(-1.75)
constant term (math.)	04391** (2.56)	1.1367* (1.70)
sample size	1139	1139
goodness of fit	0.46	0.489
local control	clogged	be
time control	clogged	be

Note: Superscripts *, **, and *** indicate that the test of significance with a confidence level of 90%, 95%, and 99%, respectively, is passed, and t-values are in parentheses, as follows.

4.2.2. Robustness Test

Table 4. Robustness test results

variant	Substitution of explanatory variables			Substitution of explanatory variables		Truncation (p)
	Reasonable share of industrial sulphur dioxide emissions to generation	The proportion of reasonable industrial wastewater discharge to generation	Reasonable share of industrial solid waste emissions versus generation	Percentage of green credit	Percentage of green insurance	
G	0.2117*** (3.26)	0.1857** (4.98)	0.1621*** (7.19)	0.9225*** (15.98)	0.0141** (2.54)	0.2117*** (3.28)
control variable	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
constant term (math.)	0.4237*** (47.34)	0.4101*** (19.82)	0.4239*** (38.20)	0.1864*** (35.11)	0.1843*** (40.43)	0.4236*** (47.55)
sample size	1139	1139	1139	1139	1139	1139
goodness of fit	0.561	0.581	0.435	0.466	0.463	0.519
local control	be	be	be	be	be	be
time control	be	be	be	be	be	be

In order to ensure the reliability of the research results, robustness tests such as replacing explanatory variables, replacing explanatory variables, and ending treatment are carried out, and the single ecological environment pollution management indicators (such as the proportion of reasonable industrial sulfur dioxide emissions and generation, the proportion of reasonable industrial wastewater emissions and generation, the proportion of reasonable industrial solid waste emissions and generation) are taken as the replacing explanatory variables, and the level of green finance development is Replacing a single green financial indicator (the proportion of green credit and the proportion of green insurance), the regression analysis is re-run, and the results are shown in Table 4.The impact of green finance on a single ecological environmental pollution management indicator is still significantly positive, and green finance has an inhibitory effect on different types of ecological environmental pollution emissions, which indicates that the results of the baseline regression in the previous section have a certain degree of robustness. The regression results after replacing the explanatory variables are consistent with the benchmark regression, further verifying its robustness, and thus hypothesis H1 is verified.

4.2.3. Tests for Mediating Effects

In order to verify the hypothesis H2, the stepwise regression method is used to construct the mediation effect model, without considering, considering the mediation effect when the green financial development of the ecological environment pollution management, the calculation model is set as follows:

$$P_{it} = \propto_0 + \propto_1 G_{it} + \propto_2 C_{it} + \theta_{it} + \beta_{it} + \varepsilon_{it} \quad (2)$$

$$S_{Tit} = \propto_0 + \mu_1 G_{it} + \gamma C_{it} + \theta_{it} + \beta_{it} + \varepsilon_{it} \quad (3)$$

$$P_{it} = \propto_0 + \mu_2 S_{Tit} + \propto_1' G_{it} + \propto_2 C_{it} + \theta_{it} + \beta_{it} + \varepsilon_{it} \quad (4)$$

Where:S_{Tit} ,P_{it} ,G_{it} are the innovation level, ecological environment pollution control level and green financial development level of cityi in the yeart ,μ_1 is the regression coefficient of green financial development on science and technology innovation,γ is the regression coefficient of the effect of control variables on the level of science and technology innovation, μ_2 is the regression coefficient of the effect of the level of science and technology innovation on the ecological environment pollution control, and $\propto_1'$ is the direct effect of the effect of the development of green financial development on the ecological environment pollution control after controlling for intermediary variables. C_{it} is the control variable and ε_{it} is the random disturbance term.

The results of the mediation effect test are shown in Table 5.The regression coefficient in the first column represents the impact of green financial development on the level of innovation, and from the results, it can be seen that green financial development has a positive impact on the level of innovation at the 95% confidence level, i.e., for every percentage point of the level of green financial development, the level of innovation will be increased by 0.0903 percentage points. The regression coefficient in the second column is the impact of green financial development on ecological environment pollution governance, and from the results, green finance significantly improves the level of ecological environment pollution governance through the level of innovation. The test F-statistic of the stepwise regression method shows that the innovation level plays a mediating role in the green finance on the ecological and environmental pollution governance in the Yangtze River Basin, thus hypothesis H2 is argued.

Table 5. Mediating effects test regression results

variant	regression coefficient	
	S_T	P
G	0.0903* (1.74)	0.1137*** (4.05)
S_T		0.0077*** (2.88)
control variable	Controlled	Controlled
constant term	0.5413*** (50.14)	0.1546*** (10.61)
sample size	1139	1139
F-statistic	8.52	112.02
goodness-of-fit	0.497	0.550
local control	be	be
time control	be	be

4.2.4. Heterogeneity Analysis

The Yangtze River Basin spans multiple climatic zones and economic regions, with regional differences in natural resource structure, industrial structure, policy implementation strength, and financial market maturity, resulting in different patterns and intensities of the impact of green finance on eco-environmental pollution management, necessitating a test of heterogeneity. The 11 provinces in the Yangtze River basin are categorized into upstream, midstream and downstream. The panel regression model is used to test the heterogeneity of the impact of green finance on ecological environment pollution governance, and the regression results are shown in Table 6.

Table 6. Heterogeneity test regression results

variant	regression coefficient		
	upper reaches of the Yangtze River	middle reaches of the Yangtze River	lower reaches of the Yangtze River
G	0.1199* (1.75)	0.1495* (1.94)	0.1546** (2.18)
control variable	Controlled	Controlled	Controlled
constant term	0.1649*** (6.57)	0.1331** (3.88)	0.1779** (6.38)
sample size	603	335	201
goodness of fit	0.4269	0.44	0.48
time control	be	be	be

As can be seen from Table 6, there are significant regional differences in the impact of green finance on ecological and environmental pollution management due to the influence of resource endowment, the level of economic development and the strength of policy implementation. For the upstream cities, the regression coefficient of green finance is significantly positive, indicating that green finance has strong inhibition on ecological environment pollution in the upper reaches of the Yellow River. The upstream area is rich in natural resources, geographically remote, with a relatively low level of economic development, and the ecological environment pollution mainly comes from resource extraction and primary processing industry, the development of green finance focuses on ecological protection, and should reduce the damage of resource extraction to the ecological environment. For midstream cities, the regression coefficient of green finance is significantly positive. The midstream region has industrial agglomeration development and dense population. Although the demand for resource utilization and the diversification of economic activities make the impact of green

finance on ecological pollution management somewhat diluted, it still has a significant contributing effect. For downstream cities, the regression coefficient of green finance is 0.1546 and passes the significance test with a confidence level of 95%. Compared with the upstream and midstream regions, the downstream region has more mature economic development, higher urbanization level, high population density and complex industrial structure make pollution management more difficult, and the need for pollution management is more urgent, but the region has better economic conditions and strong policy implementation, and green finance plays an important role in ecological environment pollution management.

5. Conclusion

Based on the panel data of 42 prefecture-level cities in the Yangtze River Basin, the entropy value method, two-way fixed-effects model and intermediary effect model are comprehensively applied to systematically study the mechanism of green finance's influence on ecological and environmental pollution management and its conduction paths, and the main conclusions of the study are as follows:

Green finance significantly enhances the level of ecological and environmental pollution management in the Yangtze River Basin. The results of the panel regression model show that there is a significant positive relationship between the development of green finance, indicating that green finance is able to support the development of environmental protection industries and green projects by optimizing the allocation of resources, and effectively enhance the level of ecological and environmental pollution governance in the Yangtze River Basin.

The level of innovation plays a key mediating role between green finance and eco-environmental pollution governance. The results of the mediation effect test indicate that green finance not only directly affects eco-environmental pollution governance, but also promotes the improvement of eco-environmental pollution governance by facilitating the innovation level profile.

Influenced by factors such as the level of economic development, industrial structure, and the strength of policy implementation, there is significant regional heterogeneity in the impact of green finance on ecological and environmental pollution management.

Based on the above findings, the following policy recommendations are made:

Optimizing the allocation of green financial resources. The Government should introduce targeted policies to clarify the key areas of support, such as formulating a catalog of green projects and providing tax incentives, financial subsidies and other support to guide financial institutions to increase their investment. At the same time, it should encourage the development of diversified products such as green bonds and green credits, design exclusive service programs, lower the financing threshold, and meet the capital needs at different stages.

Strengthen the drive for innovation. The government and enterprises should increase investment in environmental protection science and technology, set up a special fund to support technological research and development, and focus on breakthroughs in key technologies for pollution control. Establish a reward system for innovative achievements and recognize outstanding contributors. Encourage enterprises to apply new technologies, and give tax breaks and other support to enterprises that have significantly improved their level of governance.

Promote regional synergy according to local conditions. Differentiated policies will be formulated for different regions of the Yangtze River Basin: downstream regions can pilot green financial innovations; middle and upstream regions will focus on supporting the green transformation of traditional industries. Regional cooperation mechanisms should be established to strengthen information sharing, promote complementarity between upstream and downstream regions, and jointly enhance pollution management.

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