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Research on the Effect of Green Finance on Environmental Pollution: Evidence from EKC Framework

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ABSTRACT

Based on the Environmental Kuznets Curve (EKC) theoretical framework, this study employs panel data from 11 provinces and municipalities in the Yangtze River Basin from 2012 to 2022. We construct a two-way fixed effects model incorporating green finance variables and their interaction terms to empirically examine the impact mechanism of green finance on environmental pollution, represented by sulfur dioxide (SO_2) emissions. The analysis includes regional comparisons (upstream, midstream, downstream) and robustness tests. The findings are: (1) A significant inverted U-shaped EKC relationship is confirmed in the upstream and midstream regions of the Yangtze River Basin, but this relationship is not significant in the downstream region. (2) The development of green finance, measured by the proportion of green credit, has a significant inhibitory effect on environmental pollution in the upstream and midstream regions. Through its negative interaction with economic growth, green finance promotes the earlier arrival of the EKC inflection point. However, in the downstream region, the emission reduction effect of green finance is not significant and may even exhibit a "green transition paradox," potentially due to "greenwashing" or shifts in pollution source structures. (3) Robustness tests, including substituting pollution indicators, considering lagged effects, and comparing model specifications, consistently support the reliability of the core conclusions. The study demonstrates that green finance policies can effectively promote regional green transformation, but their effects are regionally heterogeneous. Policy design should, therefore, emphasize medium-to-long-term financial support, improve evaluation mechanisms, and implement differentiated strategies across regions.

KEYWORDS

Green finance; Environmental Kuznets Curve (EKC); Environmental pollution; Yangtze river basin; Two-way fixed effects model

1 Introduction

As China's core development region with dense population and great economic potential, the Yangtze River Basin covers 11 provinces and cities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou. However, in the long process of industrialization, the "golden waterway" facing serious challenges, deterioration of water quality, frequent water pollution incident, the problem such as biological diversity decline increasingly prominent (li hua, etc., 2020). These problems not only threat watershed ecosystem health, more pose a serious challenge to the sustainable development of economic and social. In this context, how to jointly promote "high-level ecological environment protection and high-quality economic and social development" in the Yangtze River Economic Belt has become a major proposition. The proposal of green financial system provides an innovative solution to this proposition. Ma Jun (2016) pointed out that the key measure to promote the green transformation of economy is to guide funds from polluting industries to green industries by adjusting the incentive mechanism of resource allocation. Wang et al. (2021) further explained how financial instruments such as green credit can indirectly promote green innovation through policy incentives, reducing agency costs and improving investment efficiency. Guo-jin Chen (2021), such as the use of ESG asset pricing model and the triple difference method, the empirical analysis of the green financial policy how to affect the financing cost drive enterprise green transition.

In recent years, attach great importance to the green financial development of the national and local levels. In 2016, the Chinese government issued the Guiding Opinions on Building a Green Financial System, which proposed a systematic green finance policy framework for the first time. In 2017, zhejiang, jiangxi, guizhou was selected for the green financial reform and innovation experimental zone, a series of replicable experience. For example, Quzhou in Zhejiang Province has established a carbon account system, Ganjiang New Area in Jiangxi Province has launched a carbon neutral fund, and Guizhou Province has established a "green inclusive credit" provincial agricultural credit system and established the country's first "green finance" insurance laboratory (Zhang Wei, 2023). In 2024, the bank of China and other institutions jointly issued "about further completes the financial support of the Yangtze river economic belt green low carbon and high quality development of guidance", clearly put forward to develop the green financial key task, support the development of the Yangtze river economic belt green low carbon and high quality.

Based on this background, this paper, taking the Yangtze river basin as the research object, the key selection (sichuan province) and downstream two representative provinces (jiangsu province), through the analysis of environmental kuznets curve (EKC) of the inflection point of change, to explore whether green financial policy to promote regional green development. The core hypothesis of the EKC curve was first proposed by Grossman and Krueger (1993), that is, the environment deteriorates with the growth of per capita income in the early stage of economic development. Therefore, the analysis of whether green finance accelerates the arrival of EKC inflection point in advance can strongly verify whether the policy effectively promotes the transformation of regional development mode, and then provide precise policy basis for "ecological priority and green development" in the Yangtze River Economic Belt.

2 Research design and data

At present, the domestic and foreign scholars of environmental kuznets curve (EKC) of a turning point for the study of widely. Grossman and Krueger (1993) put forward the present environmental quality and per capita income levels for the first time after the "inverted U" curve relationship, Selden and Song (1994) confirmed that the four kinds of pollutants in the air SO_2, CO_2, NO_2, SPM) there is a "inverted U" relationship to income. Xepapadeas and Amri (1995) also reached a similar conclusion. Domestically, Lu Hong CO_2 air pollutants (2000) explores our country and the relationship between per capita GDP, found that both exist interaction effect, but it is not simple "inverted U" relationship. Boqiang Lin and jiang zhu (2009) predicting the turning point of China's carbon dioxide kuznets curve theory corresponding to the per capita income. Xu Guangyue and de-yong song (2010) based on the data of provinces and cities of our country, the CO_2 emissions and per capita GDP as the main indexes to establish logarithm linear model, it is concluded that the eastern, central and western regions of the inflection point per capita GDP value. Rainieyes and liu Ming (2020) innovation in introducing green finance as endogenous variable of EKC equation, reveal the northwest province of EKC curve shape "N" on the whole. Although there are many kinds of environmental pollution indicators are defined, this study adopts the classic still SO_2 emissions as indicators of environmental pollution. In order to clearly identify whether green finance as a policy tool to adjust the EKC relationship of classic, we first introduce environmental kuznets hypothesis: Classic EKC hypothesis between economic growth and environmental pollution inverted u-shaped relationship, to test the hypothesis in the applicability of the Yangtze river basin, we in the EKC model introduces the quadratic term of GDP, and on the basis of verification and improvement.

2.1 Model construction

To test the green financial impact on the Yangtze river basin Environmental pollution mechanism, based on the Environmental Kuznets Curve (Environmental Kuznets Curve, EKC) under the theoretical framework, introducing green financial variables and build bidirectional fixed effects model. EKC hypothesis, between the economic development and environmental pollution "inverted U" relationship, namely in the early stages of economic development, economic growth will intensify pollution, when the per capita income reaches a certain level, technical progress and industrial structure optimization decline will cause pollution. In order to examine whether green finance can change this relationship, based on the classical EKC model to add green financial indicators and their interaction, model set is as follows:

2.2 Variable selection and data sources

This study selected 2012-2022 panel data of 11 provinces in the Yangtze river basin, are based on data from the national and provincial statistics yearbook (2023), China's environmental statistics yearbook (2023), the provincial branch of the people's bank of green financial statistics released annual report and the ecological environment agency bulletin. All continuous variables are taking natural logarithms, in order to eliminate heteroscedasticity and dimensional difference. Specific variables that are shown in table below.

Table 1 Variable definitions and data sources

The variable name	Variable symbol	Meaning of index	Unit	Data sources	Expected symbols
Environmental contamination	Ln_SO_2	Logarithm of sulfur dioxide emissions	10,000 tons	China Statistical Yearbook on Environment	—
Economic level	Ln_GDP	Logarithm of provincial GDP per capita (constant 2015 prices)	yuan	China Statistical Yearbook	+
Economic nonlinear term	Ln_GDP^2	The log squared term of GDP	—	Do your own calculations	–
Green finance development	GF	The balance of environmental protection credit in each province accounted for the proportion of total loans	%	Bulletin of the People's Bank of all provinces	–
Industrial structure	IS	Ratio of the added value of secondary industry to GDP	%	China Statistical Yearbook	+

In order to enhance the comparability of the data, the missing values of individual years were completed by linear imputation. The sample size was 11×11 = 121 sets of observations.

3 Empirical analysis and results

3.1 Descriptive statistics

In order to preliminarily understand the distribution characteristics of variables, the main variables were analyzed by descriptive statistics. The results are shown in the following table.

Table 2 Descriptive statistics

Variables	Number of observations	Mean	Standard deviation	Minimum	Maximum
Ln_SO_2	121	3.421	0.893	1.251	5.012
Ln_GDP	121	10.653	0.427	9.721	11.589
Ln_GDP^2	121	113.725	9.112	94.517	134.247
GF	121	0.0453	0.0091	0.027	0.066
IS	121	0.446	0.058	0.321	0.552

It can be seen from the statistical results that the SO_2 emissions vary greatly within the basin, and the ratio of the minimum value to the maximum value is nearly 4 times, indicating that the pollution level varies significantly between regions. The proportion of green credit is generally low (the average value is 4.53%), indicating that the green financial system is still in the development stage. The standard deviation of the logarithm of GDP is small, which reflects the regional concentration of economic volume.

3.2 Correlation analysis

In order to test the correlation between variables and preliminarily determine the possible multicollinearity problem, Pearson correlation analysis was performed. The results are shown in the following table.

Table 3 Variable correlation coefficient matrix

Variables	Ln_SO_2	Ln_GDP	Ln_GDP^2	GF	IS
Ln_SO_2	1				
Ln_GDP	- 0.512 * * *	1			
Ln_GDP^2	- 0.486 * * *	0.965 * * *	1		
GF	- 0.376 * *	0.532 * * *	0.518 * * *	1	
IS	0.624 * * *	−0.217	−0.198	- 0.282 *	1

*, ** and *** indicate significance at 1%, 5% and 10% significance levels, respectively.

According to the results, the correlation coefficient between Ln_GDP and Ln_GDP^2 is high (0.965), and there is a certain multicollinearity, but the nonlinear characteristics used to describe the EKC curve can still be retained at the same time. There was a significant negative correlation between Ln_SO_2 and Ln_GDP (−0.512), indicating that with the economic development, the overall pollution showed a downward trend, which was consistent with the right characteristics of the EKC hypothesis. Green finance (GF) was negatively correlated with SO_2 emissions (−0.376), indicating that the development of green finance had an emission reduction effect; The proportion of the secondary industry was positively correlated with SO_2 emissions (0.624), indicating that the industrial structure was still the main source of pollution.

3.3 Unit root test

To avoid spurious regression, three panel unit root test methods, Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS) and Fisher-ADF, are used in this paper. The test results are as follows.

Table 4 Panel unit root test results

Variables	LLC	IPS	Fisher-ADF	Stationarity conclusion
Ln_SO_2	- 3.42 * * *	- 2.91 * * *	35.72 * * *	Smooth
Ln_GDP	- 1.76 *	- 1.98 *	24.51 * *	First difference stationary
Ln_GDP^2	- 2.14 * *	- 2.08 * *	27.14 * *	First difference stationary
GF	- 3.37 * * *	- 3.12 * * *	39.62 * * *	Smooth
IS	- 1.95 *	- 2.01 * *	26.77 * *	Smooth

*, ** and *** indicate significance at 1%, 5% and 10% significance levels, respectively.

All variables passed the stationarity test after first-order difference, indicating that they can be used in panel regression analysis.

3.4 Two-way fixed effect model group regression

In order to identify the differentiated role of green finance in different development stages, this paper divides the

samples into three groups according to the economic development level of the river basin: upstream (Sichuan, Yunnan, Guizhou and Chongqing), midstream (Hubei, Hunan, Jiangxi and Anhui) and downstream (Jiangsu, Zhejiang and Shanghai), and introduces fixed effects in the dimension of province and year for regression.

Table 5 Regression results of two-way fixed effects

Variables	Upstream region	Midstream area	Lower reaches
Ln_GDP	0.524 * * *	0.418 * * *	0.276 * *
Ln_GDP^2	- 0.029 * *	- 0.021 *	−0.013
GF	- 1.874 * * *	- 1.225 * *	0.462
Ln_GDP×GF	- 0.213 * * *	- 0.148 * *	0.096 *
IS	0.837 * * *	0.629 * * *	0.415 * * *
Constant term	- 2.911 * * *	- 2.247 * * *	- 1.805 * * *
R^2	0.762	0.713	0.688
Number of samples	44	44	33

*, ** and *** indicate significance at the level of 1%, 5% and 10%, respectively.

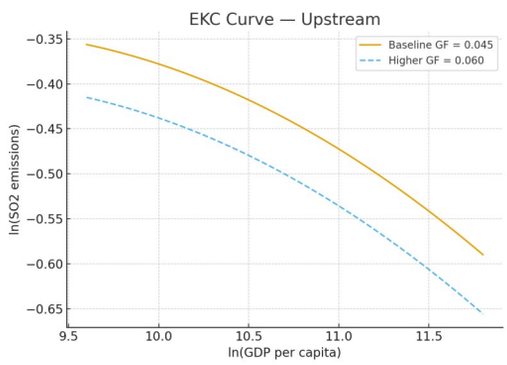

Figure 1 Environmental Kuznets curve (EKC) in the upstream region

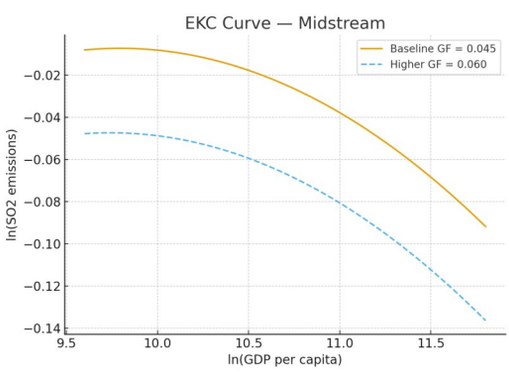

Figure 2 Environmental Kuznets curve (EKC) in the midstream region

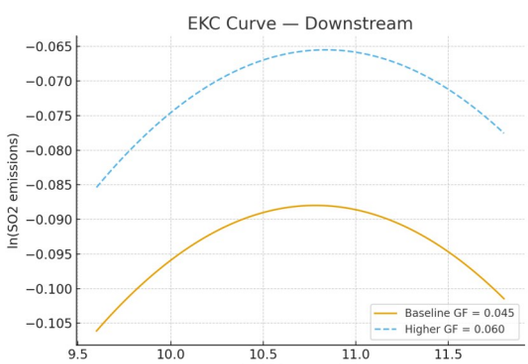

Figure 3 Environmental Kuznets curve (EKC) in the downstream region

According to the regression results, the linear coefficient of GDP is positive and the quadratic coefficient is negative in the upstream and midstream regions, indicating that there is a significant inverted U-shaped relationship, which is consistent with the EKC hypothesis. The coefficient of the interaction term of green finance is negative and significant, indicating that the development of green credit effectively weakens the promoting effect of economic growth on

pollution and promotes the early appearance of the inflection point. However, in the downstream region, the coefficient of the interaction term is positive and significant at the level of 10%, indicating that green finance aggravates the emission growth caused by economic expansion. This result may be due to the "green transition paradox" or "scale effect trap" : when pursuing green indicators, financial institutions include some loans that are not really low-carbon projects into the green credit statistics, resulting in the phenomenon of "green washing". In addition, the pollution sources in downstream areas have shifted from industrial point sources to transportation and port emissions, and the existing green financial instruments have limited restraint on these areas.

In terms of the overall fitting effect of the model, the R-squared of each group is above 0.68, indicating that the model has a strong explanatory power. The proportion of the secondary industry is significantly positive in the three regions, indicating that the industrial structure is still an important factor affecting pollution.

3.5 Robustness test

In order to verify the robustness and reliability of the model estimation results, this paper tested the results from three aspects: first, the substitution variable method was used to replace the environmental pollution index from SO_2 to the mean value of chemical oxygen demand (COD) and PM2.5 concentration; Second, the lagged term method is adopted to estimate the green finance variables with a one-period lag considering the time-lag effect of green finance policies. Thirdly, the model setting comparison method is adopted to further verify the rationality of the model setting through the comparison test between the random effect model and the fixed effect model.

3.5.1 Substitution variable method

In order to eliminate the possible bias caused by a single pollution indicator, this paper replaced SO_2 emissions with two representative indicators: chemical oxygen demand (COD) and PM2.5 average concentration, and re-performed the regression. The results are shown in the table below.

Robust regression results using alternative pollution indicators are presented in Tables 6

Table 6 Robust regression results

Variables of interest	COD model	PM2.5 model
Ln_GDP	0.473 * * *	0.501 * * *
Ln_GDP^2	- 0.026 * *	- 0.028 * *
GF	- 1.352 * *	- 1.404 * *
Ln_GDP×GF	- 0.176 * *	- 0.185 * *
IS	0.713 * * *	0.689 * * *
Constant term	- 2.137 * * *	- 2.204 * * *
R^2	0.719	0.726
Number of samples	121	121

*, ** and *** indicate significance at the level of 1%, 5% and 10%, respectively.

It can be seen from the results that there is still a significant inverted U-shaped relationship between economic growth and pollution. The first term of Ln_GDP is positive and the second term is negative, indicating that the EKC hypothesis is still valid. At the same time, the green finance variable (GF) and its interaction term remain negative and significant under different models, indicating that green finance has a robust inhibitory effect on pollution emission reduction. This result shows that the empirical conclusion of this paper does not depend on the single choice of pollution index.

3.5.2 Lagged term method

Considering that there is a time delay in the impact of green finance policies on economic behaviors, this paper re-estimates the core variable green finance (GF) with a one-period lag to test the dynamic persistence of policy effects. The regression results are shown in the table below.

Table 7 Robustness regression results of lagged terms of green finance

Variables	Coefficient estimates	T-value	Significance
Ln_GDP	0.436 * * *	5.42	0.000
Ln_GDP^2	- 0.023 * *	−2.11	0.037
GF_{t-1}	- 1.186 * *	−2.37	0.019
$Ln\_GDP×GF_{t-1}$	- 0.189 * *	−2.46	0.014
IS	0.671 * * *	6.53	0.000
Constant term	- 2.534 * * *	−4.17	0.000
R^2	0.704		

*, ** and *** indicate significance at the 1%, 5% and 10% significance levels, respectively.

It can be seen that the one-period-lagged green finance variable and its interaction term are still negative and valid at the significance level of 5%, indicating that the effect of green finance on pollution reduction has a continuous and delayed effect. This shows that the improvement of environmental quality caused by green credit expansion does not happen immediately, but is gradually reflected through industrial structure adjustment and technological innovation.

3.5.3 Comparison method of model setting

In order to further verify the robustness of the model setting, this paper uses the random effect model (REM) and the fixed effect model (FEM) to compare. The Hausman test is used to determine which model should be used. The results are shown in the table below.

Table 8 Comparison results between random effects and fixed effects models

Test items	Random effects model estimation	Fixed effects model estimation	Hausman χ^2 value	P-value	Conclusion
Ln_GDP	0.417 * * *	0.459 * * *	$\chi^2 = 28.73$	0.000	The null hypothesis is rejected and fixed effects are used
Ln_GDP²	- 0.021 *	- 0.024 * *			
GF	- 1.047 * *	- 1.218 * *			
Ln_GDP×GF	- 0.156 * *	- 0.174 * *			
IS	0.621 * * *	0.653 * * *			
R^2	0.676	0.713			

*, ** and *** indicate significance at the level of 1%, 5% and 10%, respectively.

The Hausman test results show that χ^2=28.73, p<0.01, which significantly rejects the null hypothesis of the random effect model, indicating that the fixed effect model is more suitable. This result shows that the fixed effect model can more accurately reflect the real relationship between green finance and environmental pollution under the condition of controlling the differences between provinces and years. In addition, the coefficient signs of the two models are consistent with the significance direction, which further verifies the robustness of the model conclusions.

4 Research conclusion

Based on the above three sets of robustness test results, it can be concluded that the regression conclusions of this paper are consistent under different Settings: green finance has a significant inhibitory effect on environmental pollution in the Yangtze River Basin, and its effect shows the characteristics of consistent direction and significant stability under different pollution indicators, time lags and model setting conditions. It can be seen that the model in this paper has good robustness and explanatory power.

In addition, the lag test results reveal that the green finance policy has the characteristics of time lag, that is, its emission reduction effect can be manifested only after a certain transmission period, which is consistent with the real characteristics of long investment cycle and slow payback period of green industry.

The policy implications are as follows: in the future green finance policy design, we should pay attention to the sustainability of medium and long term financial support and the improvement of evaluation mechanism, avoid the phenomenon of "green washing" caused by short-term assessment, and further improve the actual emission reduction performance of green finance.

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