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The Effect of Green Finance on Urban Ecological Economy: Evidence from the Huai River Basin

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Abstract: Against the backdrop of the coordinated advancement of the dual carbon strategy and high quality development of river basins, uncovering the mechanisms through which green finance enables the transition to an ecological economy carries substantial theoretical and practical significance. Taking the Huai River Basin, covering four provinces (and province-level municipalities and autonomous regions), as the study area and using data from 2000 to 2023, this paper innovatively constructs a comprehensive green finance index for prefecture level cities from a multidimensional perspective that includes credit, investment, insurance, bonds, funds, and carbon rights trading. Urban ecological economic efficiency is then measured via the entropy weight method within a three dimensional framework encompassing economic, ecological, and social dimensions. Employing a panel two way fixed effects model and a stepwise mediation testing procedure, the study empirically examines the impact of green finance on ecological economic development and identifies the underlying mechanisms. The results show that green finance significantly enhances the overall level of urban ecological economic performance in the Huai River Basin. This finding remains highly robust after a series of endogeneity and robustness checks, including a one period lag of the dependent variable, 1% winsorization, and the replacement of subcomponents of the dependent variable. Mechanism analysis reveals that the transmission of ecological dividends through technological innovation and industrial structure upgrading remains obstructed. The innovation channel is constrained by the long cycle of green technology research and development and delays in commercialization, while the structural channel is limited by the rigidity and path dependence of the basin's industrial structure. Heterogeneity analysis further indicates that the promoting effect is significantly stronger in cities with higher levels of environmental regulation, urbanization, and economic development.

Keywords: Green finance, ecological economy, Huai River Basin, two-way fixed effects, mediation effect.

1. Introduction

Against the backdrop of global climate change and the sustainable development agenda, fostering synergies between economic growth and environmental protection has become a shared challenge across countries. As a key financial instrument for this purpose, green finance channels societal capital toward green sectors such as energy conservation, environmental protection, and clean energy, thereby playing an increasingly important role in facilitating the green transformation of economic structures and mitigating environmental risks. China has elevated its carbon peak and carbon neutrality targets to a national strategy and is committed to establishing a comprehensive green finance system. The introduction of a series of top-level policy frameworks, including the Guidelines on Establishing the Green Financial System (2016), signals that green finance has emerged as a core driver of the country's high-quality economic development.

The interaction between green finance and the ecological economy has attracted considerable research attention in recent years. A growing body of studies has employed the coupling coordination degree model to uncover the inherent patterns and spatial characteristics of their coordinated development. In terms of measurement and spatiotemporal evolution, Jiang et al. (2025) [1], using panel data from 284 Chinese cities, applied the entropy weight method and the Dagum Gini coefficient and found that the overall level of green finance nationwide has risen but at a decelerating rate. The spatial distribution follows an "East > National > Central > West" pattern, and regional disparities have gradually narrowed, providing a basis for designing differentiated policies. Another study (2024) [2] on corporate environmental, social, and governance (ESG) performance and financial performance reports that the coupling coordination degree between the two remains modest, indicating a transitional stage, with significant variation across regions and firm types, which points to the need for firms to balance non-financial and financial goals. With respect to mechanisms, green finance exerts a direct driving effect on the green transformation of specific economic forms. Xie and Zhou (2024) [3] demonstrate that green finance serves as an effective pathway to the green development of the digital economy, operating mainly through the mediating mechanism of promoting industrial structure rationalization and advancement, and a double threshold effect is also present. Liu and He (2021) [4] further identify three key channels through which green finance promotes high-quality urban economic development: stimulating green technology innovation, guiding green household consumption, and fostering industrial structure upgrading. These effects are more pronounced in cities with lower levels of science and education, small and medium-sized cities, and those located in central and western China.

Agriculture serves as a core industry in many river basin regions, and the effect of green finance on its high-quality development has direct implications for the regional ecological–economic base. Zhang (2024) [5] directly examined this relationship and identified a double threshold effect, where the promoting effect of green finance on high-quality agricultural development varies according to both its own development level and the level of economic development; environmental regulation further reinforces this relationship. The underlying mechanism operates through two mediating paths—agricultural technological progress and agricultural resource accumulation—and the effect exhibits regional heterogeneity. Agricultural activities themselves also constitute a source of ecological pressure. A study by Wang et al. (2023) [6] on agricultural non-point source pollution in the Yangtze River Delta found an inverted U-shaped relationship between agricultural industrial agglomeration and pollution; however, when spatial spillover effects are incorporated, the relationship becomes U-shaped, suggesting that agglomeration policies in a single region may aggravate pollution in neighboring areas through spatial spillovers. Green finance, by guiding agriculture toward moderate-scale operation, optimizing industrial structure, and promoting the diffusion of green technologies, can specifically counteract these negative environmental effects of agglomeration, which carries methodological significance for the governance of agricultural non-point source pollution across administrative boundaries.

Watershed ecological-economic issues are inherently transboundary. Ecological compensation mechanisms serve as a key policy instrument for aligning upstream and downstream interests and managing cross-boundary pollution, and they intersect with both the concept and practice of green finance. China has developed distinct models of watershed ecological compensation. ZHOUL and HONGSX (2026) [7] compared the formal, centrally-led Xin’anjiang model with the informal, locally-initiated Weihe model, and found that the formal model significantly reduced industrial water pollutant emissions but could cause economic losses in upstream areas; the informal model had limited effects, underscoring the importance of adequate compensation funding and incorporating officials’ environmental performance into evaluations. Green finance can serve as an important supplementary source for ecological compensation funds. YuJ et al. (2024) [8] evaluated horizontal ecological compensation policies and found that they significantly reduced industrial wastewater discharge, yet this effect was highly contingent on vertical oversight by the central government, indicating that purely market-based approaches or inter-local government agreements may have limitations. Moreover, the success of ecological compensation also depends on public support. PengZY (2022) [9] examined ecological compensation for the South-to-North Water Diversion Project, estimating the public’s willingness to pay and willingness to accept, and identified a gap between the two. Education, income, and awareness were key determinants, suggesting that the design of green financial products or ecological compensation funds should account for the public’s cognitive basis.

2. Theoretical Analysis and Research Hypotheses

2.1. Direct Promoting Effect of Green Finance on the Ecological Economy

The ecological environment exhibits classic public goods characteristics, so traditional financial markets often suffer from market failure and unaddressed negative externalities when addressing environmental pollution. At its core, green finance internalizes environmental costs through financial instruments such as credit rationing and interest rate pricing. On the one hand, by supplying low cost, long maturity capital through instruments like green credit and green bonds, green finance directly closes the funding gaps in water treatment, ecological restoration, and environmental infrastructure construction in the Huai River Basin, producing a capital formation effect. On the other hand, green finance performs a capital guidance function by raising the financing threshold for highly polluting and energy intensive firms, channeling funds toward low carbon and environmentally friendly industries, and thereby achieving an optimal allocation of resources at the macro level. As a region where traditional agriculture and heavy industry intersect, the Huai River Basin faces considerable transition pressure; the targeted allocation of capital through green finance can directly drive the coordinated development of the local economy and the ecological environment.

H1: Green finance significantly enhances urban ecological economic performance in the Huai River Basin.

2.2. Green Finance, Industrial Structure Upgrading, and the Ecological Economy

Financial development is one of the core drivers of industrial structural change. Green finance policies are strongly industry-oriented, and their promoting effect on the ecological economy depends largely on the transmission channel of industrial structure upgrading. Specifically, through a financial penalty mechanism, such as credit constraints and higher interest rates, green finance forces traditional extensive manufacturing and heavy chemical industries in the Huai River Basin to consolidate or exit. At the same time, through a financial incentive mechanism, it supports the growth of modern services, advanced manufacturing, and green industries. This asymmetric flow of funds shifts factor resources from inefficient, high-pollution sectors to efficient, clean sectors, thereby advancing the rationalization and upgrading of the industrial structure. This greening transformation of the industrial structure directly reduces energy consumption and pollution emissions per unit of GDP, thus bringing a substantial structural dividend to the ecological economic system.

H2: Green finance improves the overall ecological economic performance of cities in the Huai River Basin by promoting industrial structure upgrading.

2.3. Green Finance, Technological Innovation, and the Ecological Economy

According to the Porter hypothesis, well-designed environmental policies and market mechanisms can trigger an innovation compensation effect among firms. Green technology innovation typically features long R&D cycles, large capital requirements, and high sunk costs, leaving firms heavily exposed to financing constraints. The development of green finance systems provides dedicated financial support—such as green funds and patent pledge financing—for environmental technology R&D and the upgrading of clean equipment, thereby effectively easing the scarcity and high cost of financing for corporate green innovation. Once firms secure such financial support, their output of green patents rises markedly. At the production stage, these advanced green technologies raise resource efficiency at the source and promote cleaner production; at the end-of-pipe treatment stage, they substantially improve pollution reduction performance. Technological innovation thus acts as a key internal engine linking green finance and the growth of the ecological economy.

H3: Green finance exerts a positive indirect effect on the ecological economy of the Huai River Basin by alleviating financing constraints and stimulating urban green technology innovation, as reflected in the level of patent grants.

3. Research Design

3.1. Model Construction

3.1.1. Benchmark Regression

To estimate the overall effect of green finance on urban ecological economic development in the Huai River Basin, we employ a panel two way fixed effects model as the baseline specification. This model effectively controls for city heterogeneity that is constant over time, as well as for macroeconomic or policy shocks that vary over time but affect all cities simultaneously. The model is specified as follows:

$$EE_{it} = \alpha_0 + \alpha_1 GF_{it} + \sum_{k=1}^{n} \beta_k Controls_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

In this equation, subscript i indexes prefecture-level cities and t indexes years. The dependent variable, EE_{it}, is the composite ecological economic index of city i in year t; the core explanatory variable, GF_{it}, is the green finance index of city i in year t; $Controls_{kit}$ denotes a vector of control variables, including GDP per capita, environmental regulation intensity, urbanization rate, degree of government intervention, and industrial structure; The term μ_i represents city fixed effects, which absorb time invariant, unobserved city specific characteristics such as geographic location, natural resource endowments, and historical and cultural background; The term λ_t represents time fixed effects, which control for temporal shocks including macroeconomic cycles and changes in national environmental policies. ε_{it} is the stochastic disturbance term.

In this specification, α_1 is the coefficient of primary interest. It measures the direction and magnitude of the direct effect of green finance on the ecological economy. A significantly positive estimate of α_1 would indicate that green finance development significantly enhances urban ecological economic performance in the Huai River Basin, thereby lending support to the core hypothesis of this study.

3.1.2. Mediation Effect

Green finance may not only exert a direct effect on the ecological economy but also generate indirect impacts through mechanisms such as stimulating green technology innovation and promoting industrial structure upgrading. To empirically test these potential transmission channels, we follow the stepwise mediation testing procedure proposed by Wen et al. (2014) and, building on the baseline model (Equation 1), specify the mediation model as follows:

$$M_{it} = \gamma_0 + \gamma_1 GF_{it} + \sum_{k=1}^{n} \beta_k Controls_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

$$EE_{it} = \rho_0 + \rho_1 GF_{it} + \rho_2 M_{it} + \sum_{k=1}^{n} \beta_k Controls_{kit} + \mu_i + \lambda_t + \varepsilon_{it}$$

In these equations, M_{it} denotes the mediator variable; in this study, it refers to the number of patent grants (capturing the technological innovation effect) and industrial structure (capturing the industrial upgrading effect), respectively. All other variables are defined as in the baseline model (Equation 1).

The logic of the mediation test proceeds as follows:

First, we assess whether the total effect coefficient α_1 in Equation (1) is statistically significant. If it is, we move to the next step;

Second, Equation (2) is estimated to examine whether green finance affects the mediator M_{it}. A significant coefficient γ_1 would indicate that green finance indeed fosters technological innovation or industrial structure upgrading.

hird, the core explanatory variable and the mediator are included simultaneously in the regression model, as specified in Equation (3). If both the coefficient on green finance ρ_1 and the coefficient on the mediator ρ_2 are significantly positive, and the absolute value of ρ_1 is smaller than the total effect α_1 or its significance level decreases, this points to a partial mediation effect. If either γ_1 or ρ_2 is not significant, the bootstrap method is applied to test the significance of the indirect effect $(\gamma_1 \times \rho_2)$, ensuring the rigor of the transmission mechanism analysis.

3.2. Indicator Measurement

3.2.1. Dependent Variable: Ecological Economic Index

To comprehensively measure green development in Huai River Basin cities beyond GDP, we construct an ecological economic index (EE) as the dependent variable. This multidimensional indicator integrates economic performance, ecological environment, and social progress using the entropy weight method applied to fixed capital stock, energy consumption, and environmental pollution data. Higher EE scores reflect stronger green development and better coordination between economic growth and environmental protection.

Table 1. Measuring Urban Ecological Economic Efficiency

Category	Indicator	Description
Input indicators	Capital input	Capital stock estimated by the perpetual inventory method (10,000 yuan)
	Labor input	Year-end employment (10,000 persons)
	Land input	Built-up area (sq. km)
	Energy input	Total electricity consumption (10,000 kWh)
	Water resource input	Total water consumption (100 million m³)
Desirable output	Economic output	Real GDP (100 million yuan)
Undesirable outputs	Industrial three wastes	Industrial sulfur dioxide emissions (10,000 tons)
		Industrial smoke and dust emissions (10,000 tons)
		Industrial wastewater discharge (10,000 tons)

3.2.2. Core Explanatory Variable: Green Finance Index

Existing studies often measure green finance at the provincial level or rely on a single credit indicator, making it difficult to capture the full picture of green finance development in prefectural cities. Departing from this practice, and adopting a multi-layered financial market perspective, this study constructs a green finance evaluation system for prefectural cities that integrates multiple dimensions including credit, investment, insurance, bonds, funds, and carbon rights trading. The specific measurement proceeds as follows. First, we systematically collect data on a set of multidimensional indicators: the share of environmental project credit, the ratio of environmental pollution control investment to GDP, the penetration of environmental pollution liability insurance, the development of green bonds, the share of green funds, and the depth of green equity development (covering carbon trading, emission rights trading, etc.). Second, we standardize the raw data to remove differences in measurement units and scales. Finally, we apply the entropy weight method (or principal component analysis) to determine the weight of each indicator and synthesize a composite green finance index (GF) at the prefectural city level. A higher GF value reflects a richer green financial product system and a stronger orientation of financial resources toward green industries.

Table 2. Evaluation indicator system for green finance development level

Category	Indicator	Description	Measurement	Attribute
Green finance development	Green credit	Proportion of environmental project credit	Total environmental project credit / Total credit	Positive
	Green investment	Ratio of environmental pollution control investment to GDP	Environmental pollution control investment / GDP	Positive
	Green insurance	Penetration of environmental pollution liability insurance	Premium income of environmental pollution liability insurance / Total premium income	Positive
	Green bond	Development level of green bonds	Total green bond issuance / Total bond issuance	Positive
	Green support	Proportion of fiscal environmental protection expenditure	Fiscal environmental protection expenditure / General budget expenditure	Positive
	Green fund	Proportion of green funds	Total market value of green funds / Total market value of all funds	Positive
	Green equity	Depth of green equity development	(Carbon trading + energy consumption rights trading + emission rights trading) / Total equity market trading volume	Positive

3.2.3. Control Variable

To mitigate endogeneity bias arising from omitted variables and to isolate the net effect of green finance on the ecological economy, this study follows the relevant literature and controls for a set of city-level characteristics that may influence ecological economic development. These variables are defined as follows:

(1) Economic development level (ln_PerGDP), measured as the natural logarithm of per capita GDP. The stage of economic development determines infrastructure capacity and directly shapes residents' demand for environmental quality;

(2) Environmental regulation intensity (ER), proxied by government spending on environmental protection relative to a benchmark or by the completion rate of emission reduction targets. Stricter environmental regulation tends to force firms toward green transformation; (3) Urbanization rate (UR), measured as the share of permanent urban residents in the total population. Population agglomeration and industrial restructuring during urbanization exert complex effects on ecological carrying capacity; (4) Government intervention (Gov), captured by the ratio of local general budgetary expenditure to GDP, reflecting the local government's capacity for direct economic intervention and resource reallocation; (5) Industrial structure (IS), measured by the share of value added of the tertiary sector in GDP (or the ratio of the tertiary sector to the secondary sector). Industrial structural upgrading is typically accompanied by declining energy intensity and thus constitutes an important determinant of the ecological economy.

3.3. Data Source

The study focuses on four provincial-level regions in China over the period 2000–2023 for the construction of relevant indicators. The new quality productive forces index and its subcomponents are derived from a specially designed indicator system. The provincial marketization index is drawn from the Marketization Index of China's Provinces Report (2018) compiled by Wang et al. (2019) and is extended using the average annual growth rate of the historical series. Data on industrial robot installation density come from the International Federation of Robotics (IFR). All other data are sourced from the China Statistical Yearbook (2010–2023) and related publications. The main empirical analysis is conducted on a panel of 432 prefectural city–year observations in the Huai River Basin covering the period 2006–2021.

Descriptive statistics reveal pronounced spatiotemporal variation. The ecological economic index (mean 0.1097) and green finance index (mean 0.2881) both indicate early-stage development, with wide min-max gaps reflecting considerable inter-city imbalances in green development quality and financial resource concentration. Control and mechanism variables also vary substantially—urbanization rates range from 12.57% to 86.90%, and patent grants show high volatility—capturing the regional heterogeneity of the Huai River Basin, where traditional agricultural areas coexist with highly industrialized zones.

Table 3. Descriptive Statistical Analysis

Variable	Symbol	N	Mean	SD	Min	Median	Max
Composite ecological economic index	EE	432	0.1097	0.0568	0.0414	0.0952	0.4029
Green finance index	GF	432	0.2881	0.0792	0.1616	0.2708	0.4878
per capita GDP	ln_PerGDP	432	10.5493	0.7377	8.2963	10.5727	12.0698
Environmental regulation intensity	ER	432	0.0031	0.0013	0.0006	0.003	0.0079
Urbanization rate	UR	432	0.5226	0.1512	0.1257	0.5267	0.869
Government intervention	Gov	432	0.1486	0.085	0.0605	0.1342	1.4852
Industrial structure	IS	432	40.322	9.3756	17.24	40.035	62.81
patent grants	ln_Patents	432	8.3298	1.6185	2.3979	8.3823	12.9269

4. Empirical Results and Analysis

4.1. Baseline Regression Analysis

Table 3 presents the baseline regression results for the effect of green finance on the urban ecological economy in the Huai River Basin. Moving from column (1) to column (3), as control variables and year fixed effects are sequentially introduced, the estimated coefficient on the core explanatory variable—the green finance index (GF)—remains consistently positive and highly significant. Column (4) reports the results of the main baseline specification, which simultaneously controls for all city-level covariates as well as year and city two-way fixed effects. The estimated coefficient on the green finance index is 0.3058 and is statistically significant at the 1% level. This core finding provides strong empirical support for Hypothesis H1.

Table 4. Baseline regression results

Variable	(1)	(2)	(3)	(4)
	EE	EE	EE	EE
GF	0.5054**	0.4519**	0.4831***	0.3058***
	(0.0971)	(0.0989)	(0.1004)	(0.1138)
Constant	-0.0359	-0.0594	-0.1474	0.0329
	-0.0244	-0.0761	-0.1173	-0.192
Control variables	No	Yes	Yes	Yes
Year fixed effects	No	No	Yes	Yes
City fixed effects	No	No	No	Yes
N	432	432	432	432
R^2	0.4954	0.5558	0.5843	0.8631

Notes: Standard errors in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The dependent variable is the composite ecological economic index (EE).

Moreover, the baseline model exhibits strong statistical reliability in terms of both goodness of fit and econometric rigor. The R^2 of the two-way fixed effects specification in column (4) rises to 0.8631, indicating that the set of variables constructed in this study accounts for over 86% of the variation in the composite ecological economic index, which reflects excellent explanatory power. By strictly incorporating city fixed effects and year fixed effects, the model effectively partials out time-invariant city-specific characteristics, while simultaneously absorbing economy-wide external shocks including macroeconomic cycles and changes in national environmental policies. This rigorous identification strategy substantially mitigates potential endogeneity bias arising from omitted variables and further reinforces the robustness of the core finding.

4.2. Mediation Effect Test

4.2.1. Mediation Effect Test Based on 'Technological Innovation'

Theoretically, green finance can alleviate the financing constraints faced by environmentally responsible firms and supply long-term financial support, thereby stimulating green technology innovation. As patented technologies are deployed, urban energy efficiency and pollution control improve, ultimately fostering ecological economic development. Table 5 reports the mediation test results for technological innovation.

Table 5. Mediation effect test results: technological innovation

Variable	(1) Baseline model	(2) Mechanism test I	(3) Mechanism test II
	EE (Y)	ln_Patents (M1)	EE (Y)
GF(X)	0.3058***	-0.456	0.3065***
	(0.1138)	(4.4314)	(0.1113)
ln_Patents (M1)			0.0015
			(0.0018)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes

Column (1) presents the baseline total effect, where the coefficient of green finance on the ecological economy is 0.3058 ($p<0.01$), satisfying the first-step requirement for mediation analysis. Column (2) examines the effect of green finance on urban technological innovation; the estimated coefficient is not statistically significant ($p=0.918$). Column (3) includes both green finance and technological innovation in the model, and the coefficient on innovation also fails to reach statistical significance. These results indicate that, under the strict control of two-way fixed effects, the mediating channel operating through the number of patent grants is empirically not discernible.

A plausible explanation is that technological innovation involves lengthy R&D cycles, and a substantial time lag and threshold effect exist between patent grants and their conversion into tangible ecological economic benefits. The current allocation of green finance may lean more toward quick-return end-of-pipe treatment or infrastructure construction, while the efficiency of translating financial resources into breakthroughs in core front-end green technologies remains yet to be improved.

4.2.2. Mediation Effect Test Based on 'Industrial Structure'

By directing financial resources, green finance guides factor inputs away from highly polluting and energy-intensive sectors toward low-carbon and modern service industries. This reallocation is theoretically expected to raise ecological economic performance through the optimization of industrial structure. Table 6 reports the mediation test results with industrial structure as the mediator.

Table 6. Results of the mediating effect test of 'industrial structure'

Variable	(1) Baseline model	(2) Mechanism test I	(3) Mechanism test II
	EE (Y)	IS (M2)	EE (Y)
GF (X)	0.3080***	3.0689	0.3058**
	(0.1113)	(11.5958)	(0.1138)
IS (M2)			0.0007
			(0.0007)
Control variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes

After removing industrial structure from the set of control variables, the total effect of green finance on the ecological economy in column (1) remains significantly positive (coefficient=0.3080, p<0.01). In column (2), the estimated coefficient of green finance on industrial structure is positive (3.0689), consistent with the theoretical expectation that green finance contributes to raising the share of the tertiary sector, yet it does not reach statistical significance. In column (3), the effect of industrial structure on the ecological economy is also statistically insignificant.

5. Further analysis

5.1. Heterogeneity Analysis

To further examine the heterogeneous effects of green finance on the ecological economy and to enhance the practical relevance of the findings, this study conducts an in-depth heterogeneity analysis along three dimensions—environmental regulation intensity, urbanization level, and economic development foundation—using the panel dataset.

Having established the overall promoting effect of green finance on the ecological economy of the Huai River Basin through the baseline regression, the analysis proceeds to investigate whether this effect exhibits asymmetry across cities with different characteristics. Specifically, the sample is split into high and low groups based on the median values of environmental regulation intensity, urbanization rate, and per capita GDP; two-way fixed effects regressions are then estimated for each subgroup. The results are presented in Table 7.

Table 7. Heterogeneity Analysis Results

Variable	(1) High environmental regulation	(2) Low environmental regulation	(3) High urbanization rate	(4) Low urbanization rate	(5) High economic level	(6) Low economic level
	EE	EE	EE	EE	EE	EE
Green finance index (GF)	0.3760***	0.1180*	0.2606**	0.0907	0.1917**	0.0965
	(0.1233)	(0.0652)	(0.1186)	(0.0585)	(0.0761)	(0.0624)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

As shown in columns (1) and (2) of Table 6, in cities with high environmental regulation intensity, the estimated coefficient on green finance is 0.3760 and highly significant at the 1% level, whereas in cities with low environmental regulation intensity, the coefficient drops to 0.1180, only marginally significant at the 10% level. This contrast suggests that stringent environmental regulation acts as a critical catalyst for green finance to realize its full effect. In jurisdictions with tighter regulation, government monitoring and penalties for pollution are stronger, imposing binding constraints that compel firms to undergo green transformation. Under such pressure, enterprises absorb and utilize green funds more efficiently, which curbs fund diversion and greenwashing and ensures that financial resources are genuinely converted into ecological economic dividends.

Columns (3) and (4) split the sample by urbanization rate. The results show that green finance significantly promotes the ecological economy in cities with high urbanization rates (coefficient=0.2606, p<0.05), while the effect is statistically insignificant in cities with low urbanization rates. The underlying logic is that high urbanization is typically accompanied by more developed financial infrastructure, higher human capital, and a more mature service sector. These cities possess a stronger capacity to absorb funds and can rapidly channel green credit and green bonds into environmental infrastructure and clean technology applications. In contrast, cities at early stages of urbanization or dominated by traditional agriculture suffer from underdeveloped financial markets, and green projects there face long payback periods and elevated risks, leaving the channels through which finance supports the ecological economy yet to be fully opened.

Columns (5) and (6) partition the sample by the median of log GDP per capita. The results indicate that in cities with higher levels of economic development, the coefficient on green finance is significantly positive (0.1917, p<0.05), whereas it is not significant in economically lagging areas. Drawing on the Environmental Kuznets Curve (EKC) hypothesis, residents in economically advanced areas have already moved beyond the stage of merely pursuing material wealth, and their demand for a high-quality ecological environment rises sharply. The market itself is thus willing to pay a green premium for environmentally friendly products and low-carbon technologies. This endogenous demand substantially stimulates the matching of supply and demand in green financial markets, enabling financial capital to foster a virtuous cycle between the ecological and the economic spheres through cross-sector integration and industrial upgrading.

5.2. Robustness Test

To ensure the reliability and rigor of the baseline regression results and to rule out concerns driven by outliers or potential endogeneity, this study conducts three sets of robustness checks based on the available data: lagging the core explanatory variable, applying winsorization to the sample, and replacing the dependent variable.

Table 8. Robustness Test Results

Variable	(1) Lagged GF (L.GF)	(2) 1% Winsorization	(3) Alternative Y: Economic subsystem	(4) Alternative Y: Social subsystem	(5) Alternative Y: Ecological subsystem
	EE	W_EE	Economic subsystem score	Social subsystem score	Ecological subsystem score
Green finance index (GF)		0.2834***	0.3347***	0.2412**	0.3576
		(0.0963)	(0.1143)	(0.0781)	(0.2806)
L.GF	0.3291**				
	(0.1483)				
Control variables	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes

The implementation of green finance policies, the disbursement of funds for environmental projects, and the materialization of ecological economic benefits generally require a certain time horizon. Moreover, a stronger ecological economy could itself attract additional green financial inflows, raising concerns about reverse causality. To address these issues, the core explanatory variable—the green finance index—is lagged by one period (L.GF) and the two-way fixed effects model is re-estimated. As shown in column (1) of Table 7, the coefficient on the one-period-lagged green finance index is 0.3291 and statistically significant at the 5% level. This finding confirms that the driving effect of green finance on the ecological economy persists even after accounting for time lags and endogeneity biases, pointing to a long-run promoting mechanism that operates across periods.

Panel data spanning an observation period of up to sixteen years may inevitably be affected by factors such as adjustments in statistical reporting standards or idiosyncratic local policy shocks, potentially generating extreme outliers. To prevent a small number of extreme observations from dominating the parameter estimates, the dependent variable (the composite ecological economic index) and the core explanatory variable (the green finance index) are both winsorized at the 1st and 99th percentiles, and the baseline model is re-estimated. The results in column (2) indicate that after removing the influence of extreme values, the coefficient on the winsorized green finance index (W_GF) is 0.2834 and highly significant at the 1% level. This outcome further confirms that the baseline findings are by no means driven by a few anomalous observations and are highly robust.

6. Conclusions and Recommendations

6.1. Research Conclusions

As shown in Figure 1, from 2006 to 2021, the green finance index and the composite ecological economic index in the Huai River Basin rose steadily and synchronously, with the green finance system continuously improving and ecological economic quality consistently increasing. During 2015–2016, the ecological economic index experienced a brief fluctuation and decline, whereas the green finance index increased year by year, reflecting the persistent and cumulative nature of green financial resource allocation.

Empirical findings from the two-way fixed effects panel model are as follows. First, green finance significantly promotes urban ecological economic development in the basin, as indicated by a significant baseline regression coefficient and high model goodness-of-fit. Second, the conclusion holds after a battery of robustness checks—including lagging the explanatory variable, winsorization, and replacing the dependent variable—yet the effect on the purely ecological subsystem is not significant, owing to the large investment requirements and long payback periods of ecological governance, with short-term financial support manifesting primarily in economic and social dimensions. Third, the mediating channels of technological innovation and industrial structure upgrading are not yet statistically effective, constrained by time lags in green technology commercialization and the industrial rigidity of the basin, respectively.

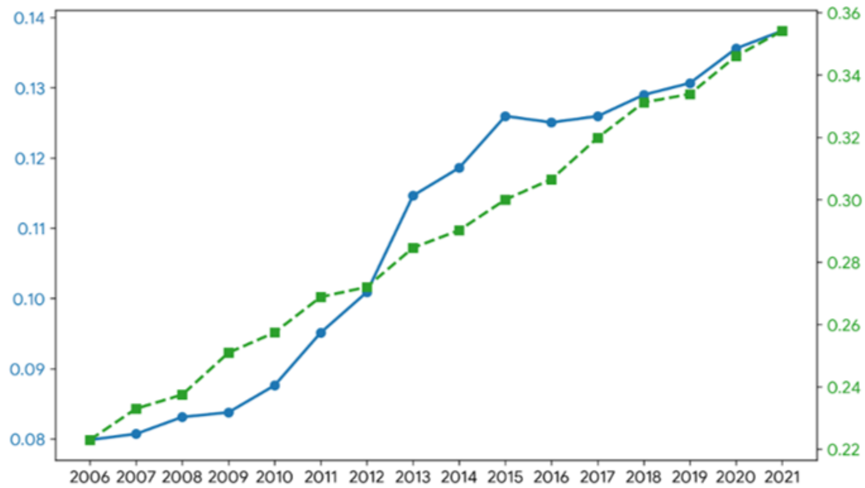

Figure 1. Trend of Urban Ecological Economy and Green Finance

6.2. Policy Recommendations

Based on these findings, the following recommendations are proposed to further unlock the enabling effect of green finance on the ecological economy and support high-quality watershed development.

6.2.1. Strengthen the Coordinated Governance of Green Finance and Watershed Environmental Regulation to Activate Policy Synergies

Empirical evidence indicates that stringent environmental regulation serves as a critical catalyst for green finance effectiveness. Local governments should fully incorporate corporate environmental performance into official evaluation systems and raise the costs of pollution violations, thereby compelling firms to actively seek green financing and curbing greenwashing at its source.

6.2.2. Implement Differentiated Regional Green Finance Policies to Precisely Overcome Development Thresholds

Areas with low urbanization and low economic development face insufficient financial market outreach and long payback periods for green projects. Establishing dedicated mechanisms for watershed horizontal ecological compensation and green credit interest subsidies can lower green financing costs in these regions.

6.2.3. Build a Full-Chain Financial Support System for Green Technology Innovation to Smooth the Pathway From R&D To Application

As green finance currently concentrates on end-of-pipe treatment and infrastructure, instruments such as green industry funds and patent pledge financing should be deployed to strengthen support for core front-end green technology R&D, effectively shortening the lag between patent grants and their transformation into ecological and economic gains.

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