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A Study on the Impact of Digital Finance on Ecological Resilience of the Yangtze River Delta Urban Agglomeration

-- The Effectiveness of Pilot Policies on Ecological Environment Compensation

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Abstracts: As the core area of China's economic development, the Yangtze River Delta city cluster faces the dual challenges of declining ecological carrying capacity and digital transformation. Digital finance, through technological empowerment and resource reallocation, may become a key driver of ecological resilience enhancement. The purpose of this paper is to explore the impact effect of digital financial empowerment on the Yangtze River Delta (YRD) urban agglomeration, to explore its mechanism of action and to further explore whether there is a chain mediation effect. This study selects the spatial panel data of the YRD urban agglomeration from 2010-2024 as a sample, and analyses them by constructing a two-way fixed-effects model, and at the same time investigates their transmission paths, and puts forward the two mediation effects of technological innovation and energy consumption, and finally, through a Double Difference Model (DID) to further discuss the effectiveness of the pilot policy of ecological compensation, and finally this paper analyses based on the above conclusions, and puts forward the relevant policy recommendations for China's digital entry and healthy development, as well as the enhancement of ecological resilience of China's cities. The empirical results show that: (1) digital finance has a facilitating effect on the ecological resilience of the Yangtze River Delta urban agglomeration. (2) Digital finance mainly plays a role in the state toughness, pressure toughness and response toughness in ecological resilience. (3) Technological innovation and energy consumption play an important role as intermediary variables in the digital financial empowerment of ecological resilience. (4) The pilot policy of ecological environment compensation is effective.

Keywords: Digital Finance; Ecological Resilience; Double Difference Model; Chain Mediation Effect

1. Introduction

As an important engine of China's economic development, the Yangtze River Delta (YRD) urban agglomeration carries nearly a quarter of the country's total economic output, and its ecological health and sustainable development capability have far-reaching impacts on the country's overall strategy. However, along with the rapid economic growth and accelerated urbanisation, the YRD region is facing serious challenges such as declining ecological carrying capacity, increasing environmental pollution and tightening resource constraints. At the same time, the rapid development of digital technology has injected new momentum into the regional economy, and digital finance, as a product of the fusion of finance and technology, has provided a potential path to crack the ‘double constraints’ of the ecological and economic dilemmas through technological empowerment and resource reallocation. In this context, how to enhance the ecological resilience of urban agglomerations through digital financial innovation, and build a long-term mechanism for synergistic coexistence of economic development and ecological protection have become key issues to be solved.

Existing studies have initially explored the relationship between digital finance and the ecological environment. Some scholars have pointed out that digital finance can indirectly improve the quality of the ecological environment by promoting green technological innovation [1], reducing the intensity of energy consumption [2], and optimizing the household consumption structure [3]. However, most of these studies focus on single-dimensional ecological indicators (e.g., pollution reduction, energy efficiency, etc.), and systematic research on the comprehensive concept of ‘ecological resilience’ is still insufficient. Ecological resilience emphasizes the ability of a system to adapt, recover and transform in the face of perturbations, covering multi-dimensional attributes such as state resilience (system stability), pressure resilience (resistance to perturbations) and response resilience (governance capacity) [4]. Existing literature has not yet revealed how digital finance contributes to the ecological resilience of urban agglomerations through multidimensional pathways, nor has it empirically examined its mechanisms (e.g., the mediating effects of technological innovation and energy consumption). In addition, although ecological compensation policies are regarded as an important tool for ecological protection, most existing studies are limited to a single area (e.g., watersheds, forests, etc.), and there is still a gap in assessing the effectiveness of policy pilots at the level of urban agglomerations.

This study aims to fill the above research gaps by systematically exploring the spatial impacts of digital finance on ecological resilience and its mechanism of action, and assessing the implementation effects of the pilot ecological compensation policy, with the Yangtze River Delta (YRD) urban agglomeration as the object of study.

The specific contributions are reflected in the following three aspects: first, breaking through the limitations of traditional single-indicator analyses, constructing a comprehensive evaluation system that includes state toughness, pressure toughness and response toughness, and revealing the multi-dimensional path of digital finance's impact on ecological toughness; second, empirically examining the conduction mechanism of ecological toughness empowered by digital finance through the introduction of technological innovation and energy consumption as the intermediary variables, to provide micro-evidence for the design of policies; Third, the policy effects of the pilot ecological environment compensation policy are assessed using the double difference model (DID) to make up for the inadequacy of existing studies in assessing the policy effects at the city cluster level.

To achieve the above objectives, this study adopts the spatial panel data of 27 prefecture-level cities in the Yangtze River Delta (YRD) from 2010 to 2024, and constructs a two-way fixed effects model and a mediated effects model, supplemented with a double-difference method for policy evaluation. The study finds that digital finance has a significant contribution to the ecological resilience of the Yangtze River Delta urban agglomeration, and this effect is realized through the mediating path of technological innovation and energy consumption; the pilot ecological environment compensation policy also effectively enhances the ecological resilience of the pilot cities. The findings of the study provide theoretical basis and practical reference for optimizing the development mode of digital finance, strengthening the support of technological innovation and improving the ecological compensation policy.

2. Literature Review and Hypothesis

2.1. Analysis of the Impact of Digital Finance on the Ecological Resilience of Urban Agglomerations

Song (2017) used a panel data model with provincial data as a sample and found that the development of digital finance has a positive effect on the improvement of the ecological environment by enhancing the level of green technology innovation [5]. Guo Feng et al. (2020) constructed a digital inclusive finance index, and the study showed that the development of digital finance can reduce the intensity of energy consumption and indirectly promote the improvement of ecological environment quality [6]. Based on Chinese household tracking survey data, Zhang Xun et al. (2019) found that digital finance helps to alleviate the credit constraints of households and prompts them to adopt a more environmentally friendly consumption pattern, thus positively affecting the ecological environment [7].

However, most of the existing studies focus on macro-level ecological environment indicators, and there are relatively few studies on the comprehensive concept of ecological resilience of urban agglomerations. In terms of the spatial structure and synergistic development of urban agglomerations, digital finance may enhance the ecological resilience of urban agglomerations by optimising resource allocation and promoting industrial upgrading. Based on this, this paper proposes hypothesis 1.

Hypothesis 1: Digital finance contributes to the ecological resilience of urban agglomerations.

2.2. Mechanisms of Digital Finance on Ecological Resilience of Urban Agglomerations

Fang Jianchun et al. (2018) found that the development of digital finance can improve the resource utilization efficiency of enterprises, thus enhancing the state resilience of the ecosystem [8]. Through empirical analyses of cities, Zhao Xiaowei et al. (2019) point out that digital finance can enhance the ability of cities to cope with external pressures, i.e., stress resilience according to this study [9]. Ma Yong et al. (2021) showed that digital finance promotes the flow of financial resources to the environmental protection industry, which helps to enhance the resilience of the ecosystem [10].

However, existing studies lack systematic analyses of the dimensions of digital finance specifically acting on ecological resilience. Considering that the ecological resilience of urban agglomerations includes state resilience, pressure resilience and response resilience, digital finance may play different but interrelated roles. Based on this, this paper proposes hypothesis 2.

Hypothesis 2: Digital finance improves the ecological resilience of cities by acting on state resilience, pressure resilience, and response resilience.

2.3. Technological Innovation and Energy Consumption as Mediating Variables Play a Significant Role in the Impact of Digital Finance on the Ecological Resilience of Urban Agglomerations

Using a panel threshold model, Wang Xin et al. (2019) found that digital finance positively affects green development by promoting technological innovation and thus green development [11]. Dong Yun et al. (2020) pointed out that the development of digital finance provides more financial support and financing channels for enterprise technological innovation, thus promoting the research and development and application of eco-friendly technologies [12]. Liu Zhijiao (2023) analyzed through the construction of the mediation effect model, pointed out that digital finance on the one hand can directly enhance the economic resilience of the city, on the other hand can indirectly improve the economic resilience level of the city through the path of urban consumption level, investment level, education investment and industrial diversification [13]. Xiong Hu et al. (2021) empirical research shows that technological innovation plays a mediating role between digital finance and environmental pollution reduction [14]. Xiao Yuanfei (2024) and other tests found that digital finance has a stronger effect on the improvement of carbon emission performance in areas with high levels of traditional financial development and agglomeration and low levels of marketisation, and at the same time, digital finance effectively improves the performance of urban carbon emissions by accelerating industrial agglomeration and enhancing the level of green innovation, and improving the government's environmental protection work will help to bring into play the improvement effect of digital finance on carbon emission performance[15]. The current research is not yet perfect on the mediating mechanism of technological innovation in the impact of digital finance on the ecological resilience of urban agglomerations. Digital finance may enhance the ecological resilience of urban agglomerations by supporting technological innovation. Based on this, this paper proposes hypothesis 3.

Hypothesis 3: Technological innovation and energy consumption as mediating variables play a significant role in the impact of digital finance on the ecological resilience of urban agglomerations.

2.4. Effectiveness of Pilot Policies on Ecosystem Compensation

For the study of ecological environment compensation policy, Shen Manhong et al. (2017) found that the policy promoted the improvement of the ecological environment of the watershed to a certain extent through the case analysis of the ecological compensation policy in the watershed of Zhejiang Province [16]. Ke Shuifa et al. (2018) assessed the forest ecological compensation policy and concluded that the implementation of the policy has improved the protection level of forest resources [17]. Wu Weiguang et al. (2019) studied the marine ecological compensation policy and pointed out that the policy helps to improve the health of marine ecosystems [18].

However, most of the existing studies focus on the assessment of the effectiveness of a single type of ecological compensation policy, and there are fewer studies on the effectiveness of pilot ecological compensation policies at the level of urban agglomerations. Given that the cities of Anqing and Chizhou will start to implement the pilot ecological environment compensation policy from 2019, it is necessary to assess its impact on the ecological resilience of city clusters. Based on this, this paper proposes hypothesis 4.

Hypothesis 4: The pilot policy of ecological environment compensation policy has effectiveness.

3. Methodology

3.1. Data and Variables

Considering the availability of data, therefore, this paper adopts the spatial panel data based on the data samples of 27 prefecture-level cities in the Yangtze River Delta region from 2010 to 2024 for the study. The relevant data come from the websites of authoritative institutions and various authoritative statistical yearbooks, including China Statistical Yearbook, China Financial Statistical Yearbook, Global Findex, China

Research Data Platform, China Public Policy and Green Development Database, Wind Database, and other national and provincial and municipal statistical yearbooks, environmental status bulletins and some professional statistical yearbooks, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, etc. The data are collected from the websites of the authoritative institutions, and various authoritative statistical yearbooks. China Science and Technology Statistical Yearbook', "China Energy Statistical Yearbook", "China Agricultural Statistical Yearbook", "China Industrial Statistical Yearbook", "China Tertiary Industry Statistical Yearbook". Some missing values were obtained by interpolation.

3.1.1. Explained Variables:

Ecological Resilience (ER) mainly measures the comprehensive level of a city's ability to constrain pollution emissions, maintain ecological status and improve governance when facing ecological system pressure or sudden shocks. Referring to the research of Guo Haihong and Liu Xin (2021) [19], while drawing on Zhang Jipeng and Peng Jingqiu's (2022) environmental quality performance assessment method, and taking into account the economic and social characteristics of the city (2023), the city's Ecological Resilience Index is decomposed into three sub-dimensions, namely, state resilience index, pressure resilience index, and response resilience index, which collectively support a holistic chained system of urban ecological resilience indexes, with the three secondary indicators are specifically measured by 14 tertiary indicators (see Table 1) [20]. Since different indicators have positive and negative impacts on the total resilience index, the method of Zhou (2021) [21]and Wang Jun et al. (2021) [22] was used to dimensionlessly process the values of the indicators, and the entropy method was used to assign weights to comprehensively measure the ecological environment resilience index of each city.

Table 1. Indicator system for measuring urban ecological resilience

Primary Indicator	Secondary Indicator	Tertiary Indicator	Unit	Direction
Ecological Resilience Index (ER)	State Toughness Index (UESI)	Water resources per capita	Cubic meter per person	Forward direction
		Green coverage rate of built-up area	%	Forward direction
		Green park area per capita _ Municipal District	Hectare per 10,000 people	Forward direction
		Built-up area per capita _ Municipal District	Square hectare per 10,000 people	Forward direction
	Pressure Resilience Index (UEPI)	Per capita industrial wastewater discharge	Tons per person	negative
		Per capita industrial sulfur oxide emissions	Tons per person	negative
		Per capita industrial soot emissions	Tons per person	negative
		Per capita carbon emissions	Tons per person	negative
		Average annual $PM_{2.5}$ concentration	Micrograms per cubic meter	negative
	Response Resilience Index (UEMI)	Industrial sulfur dioxide removal rate	%	Forward direction
		Industrial soot removal rate	%	Forward direction
		Harmless treatment rate of household garbage	%	Forward direction
		Centralized treatment rate of sewage treatment plant	%	Forward direction

	Comprehensive utilization rate of industrial solid waste	%	Forward direction

3.1.2. Core Explanatory Variables

With reference to the research of Guo Feng et al. (2020) on Digital Finance Index (DFI) [23], this paper constructs a digital inclusive finance evaluation system from three dimensions: coverage breadth, depth of use of digital finance and degree of financial digitalization, and carries out dimensionless processing on the index. The indicators are shown in Table 2.

Table 2. Digital financial inclusion evaluation system

Primary Indicator	Secondary Indicator		Specific Index
Coverage span	Account coverage		Number of Alipay accounts per 10,000 people
			Proportion of Alipay users with tied cards
			The average number of bank cards bound to each Alipay account
Service depth	Payment business		Number of payments per capita
			Per capita payment
			High frequency (50 or more annual active users) The proportion of active users who are active once a year or more
	Monetary fund operations		Per capita number of Yu 'e Bao pens purchased
			Per capita purchase amount of Yu 'e Bao
			The number of Alipay users who purchased Yu 'e Bao per 10,000
	Credit business	Personal consumption loan	There are Internet consumer loan users per 10,000 Baochengnian payment users
			Number of loans per capita
			Loan amount per capita
		Small and micro business operator	There are the number of users of small and micro business loans on the Internet in every ten thousand pay Baochengnian users
			Number of loans per household of small and micro operators
			Average loan amount of small and micro operators
	Insurance business		The number of insured Alipay users per 10,000
			Number of insurance transactions per capita
			Per capita amount insured
	Investment business		The number of Alipay users participating in Internet investment and financial management per 10,000
			Number of investments per capita
			Per capita investment
	Credit business		Number of calls per person of natural person credit
			The number of users using credit-based services per 10,000 Alipay users (including finance, accommodation, travel, social networking, etc.)
Degree of digitization	Mobile informatization		The proportion of mobile payment transactions
			The proportion of mobile payment amount
	materialization		Average loan interest rate for small and micro business operators
			Average personal loan interest rate
	Credit transformation		The proportion of the number of Alipay pens
			The proportion of the payment amount

		Proportion of Sesame credit waivers (more than all deposits required)
		The proportion of Sesame credit exemption amount (more than the total deposit required)
	facilitation	The proportion of the number of QR code payments by users
		The proportion of the amount paid by the user's QR code

At the same time, this paper refers to the research of Guo Feng et al. (2020) and assigns weights to indicators through coefficient of variation method and analytic hierarchy process [24]. The weights of indicators are shown in Table 3.

Table 3. Index weight results

Total Index	Primary Index	Secondary Index
Digital finance index	Coverage breadth (54.0%)	
	Depth of use (29.7%)	pay (money) (4.3%)、money fund (6.4%)、creditworthiness (10%)、 bound (16 0%)、investors (25. 0%)、Credit and loan (38 3%)
	Digital level (16.3%)	Credit (9.5%), convenience (16.0%), affordability (24.8%）,and mobility (49.7%)

3.1.3. Intermediary Variables:

Technological innovation, green patent refers to the patent authorization of technological innovation achievements related to environmental protection, resource conservation, sustainable development, etc. The greater the number of green patents granted by a region, enterprise or country, the stronger its R&D investment and innovation ability in the field of green technology. In this paper, the number of green patent grants is used as a measure of technological innovation and is used to construct intermediary variables.

Energy consumption refers to the amount of energy consumed by a country (region) for each unit of GDP produced in a certain period of time. This index can comprehensively reflect the energy utilization efficiency of a country or region in economic activities, reflecting the relationship between economic growth and energy consumption. The lower the value, the higher the energy utilization efficiency and the lower the dependence of economic development on energy. In this paper, energy consumption is used as the intermediate variable through the following formula. Energy consumption = Total energy consumption (tons of standard coal)/GDP (ten thousand yuan).

3.1.4. Control Variables:

In this paper, with reference to Chu Erming et al. (2023) [25], the following four variables are selected as control variables: (1) Income level, which is measured by the logarithm of per capita GDP to represent the economic development level of the city. (2) Industrial structure, measured by the ratio of the added value of the secondary industry to that of the tertiary industry. (3) Opening to the outside world is measured by the proportion of foreign investment actually used in a region to GDP, that is, the level of foreign investment. (4) Population density, expressed as the logarithm of the ratio of the permanent population of the prefecture-level city to the area of the administrative area.

3.2. Descriptive Statistics

Table 4. Descriptive statistical results

	Variable Name	Sample Size	Maximum Values	Minimum Value	Average Value	(Statistics) Standard Deviation	Median
Explanatory variable	Digital finance	405	2.579	1.627	2.312	0.227	2.39
Explained variable	Ecological resilience	405	0.054	0.02	0.032	0.005	0.032

	State toughness	405	0.006	0.002	0.003	0.001	0.003
	Response toughness	405	0.044	0.011	0.022	0.005	0.021
	Pressure toughness	405	0.007	0.006	0.007	0.003	0.007
Intermediate variable	Technological innovation	405	4.125	0.845	2.832	0.626	2.933
	Energy consumption	405	3.617	0.822	2.169	0.547	2.862
Control variable	Income level	405	5.49	4.188	4.984	0.264	5.022
	Industrial structure	405	2.889	0.313	1.028	0.365	0.986
	Open to the outside world	405	0.102	0.001	0.028	0.022	0.026
	Population density	405	3.641	2.286	2.863	0.239	2.843

As shown by the descriptive statistical analysis in Table 4, this study evaluates the data of different variables to understand their distribution and relative differences. The standard deviations of digital finance, ecological resilience, technological innovation, income level, industrial structure, and population density are all smaller than the mean, and the absolute values differ significantly. The overall smallness of the medium standard deviation data indicates that the distribution of the sample data is relatively concentrated.

4. Model Construction

4.1. Two-way Fixed Effects Model

In order to investigate the impact of green finance on the high-quality development of the economy in 31 provinces and cities, and to test hypotheses 1 and 2, the econometric baseline model Eqs. (1)-(4) are constructed as follows:

$$ER_{it} = \alpha + \beta DFI_{it} + \sum_{k=1}^{4} \gamma_k \, Control_{kit} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

$$ER1_{it} = \alpha_1 + \beta_1 DFI_{it} + \sum_{k=1}^{4} \gamma_{1k} \, Control_{kit} + \mu_i + \lambda_t + \epsilon_{1it} \quad (2)$$

$$ER2_{it} = \alpha_2 + \beta_2 DFI_{it} + \sum_{k=1}^{4} \gamma_{2k} \, Control_{kit} + \mu_i + \lambda_t + \epsilon_{2it} \quad (3)$$

$$ER3_{i} = \alpha_3 + \beta_3 DFI_{it} + \sum_{k=1}^{4} \gamma_{3k} \, Control_{kit} + \mu_i + \lambda_t + \epsilon_{3it} \quad (4)$$

where, i denotes city, t denotes year, ER_{it} denotes ecological resilience, $ER1_{it}$, $ER2_{it}$, $ER3_i$ denotes state resilience, response resilience, and stress resilience, respectively, DFI_{it} is the digital finance index, $Control_{kit}$ is a control variable, μ_i is a city fixed effect, λ_t is a time fixed effect, and ϵ_{it}、ϵ_{1it}、ϵ_{2it}、ϵ_{3it} is a random perturbation term.

4.2. Mediating effect model

In order to explore the moderating effect played by technological innovation and energy consumption in digital finance on ecological resilience and to test hypothesis 3, this paper adopts the stepwise regression method to construct the mediating effect model (5)–(8).

$$ER_{it} = \alpha_1 + \beta DFI_{it} + \sum_{k=1}^{n} \gamma_k \, Control_{kit} + \mu_{i1} + \lambda_{t1} + \epsilon_{it1} \tag{5}$$

$$TI_{it} = \alpha_2 + \beta_2 DFI_{it} + \sum_{k=1}^{n} \gamma_{2k} \, Control_{kit} + \mu_{i2} + \lambda_{t2} + \epsilon_{it2} \tag{6}$$

where EC_{it} is the mediating variable for technological innovation, and the rest of the variables have the same names as above.

4.3. Double Difference Modelling

In order to test the effectiveness of the pilot policy of ecological environmental compensation policy and to verify hypothesis 4, the following double difference model (9) is constructed.

$$ER_{it} = \alpha + \beta_1 Treat_i + \beta_2 Post_t + \beta_3 Treat_i \times Post_t + \sum_{k=1}^{n} \gamma_k Control_{kit} + \mu_i + \lambda_t + \epsilon_{it} \tag{7}$$

Where,ER_{it} is ecological resilience,$Treat_i$ indicating whether it is a virtual variable of pilot cities (1 for Anqing, Chizhou, Chuzhou, Hefei, Ma 'anshan, Tongling, Wuhu and Xuancheng, and 0 for other cities),$Post_t$ a virtual variable indicating the implementation time of the policy (1 after 2019, 0 before),$Treat_i \times Post_t$ an interaction term,$Control_{kit}$ a control variable,μ_i an individual fixed effect,λ_t and a time fixed effect.ϵ_{it} Is a random disturbance term.

5. Empirical Results

5.1. Study on the Impact of Digital Finance on the Ecological Resilience of Urban Agglomeration

The results of joint hypothesis test (F-test) and Hausman test are shown in Table X. In this paper, a fixed effect model (FE) is selected. We establish a time-individual bivariate fixed effect model to complete the empirical study on the ecological resilience of 27 prefecture-level cities in the Yangtze River Delta.

Table 5. Model selection

Check type	Statistic	P	Conclusion
F test	23.39	0.000***	FE model
Hausman test	0.93	0.008***	FE model

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively

As can be seen from the regression results of the impact of digital finance on the ecological resilience of 27 urban agglomerations in the Yangtze River Delta in Table 5, the P-value of significance is 0.000***, showing a significant level and rejecting the null hypothesis. Therefore, the model is effective. At the same time, available digital finance has a significant role in promoting ecological resilience in each city, and should continue to increase efforts to unswervingly promote the development of digital finance.

Table 6. Regression results of the impact of digital finance on urban ecological resilience

Variable	Coefficient	Standard Error	t	P	R^2	F
const	-0.031	0.005	-6.586	0.000***	within = 0.603 between = 0.312 overall = 0.46	F = 113.215 P = 0.000***
Digital finance index	0.008	0.001	7.198	0.000***		
Income level	0.006	0.001	4.376	0.000***		
Industrial structure	-0.005	0.001	-6.374	0.000***		
Open to the outside world	-0.013	0.009	-1.343	0.180		
Population density	0.007	0.001	5.785	0.000***		

Dependent variable: urban ecological resilience. Note: ***, ** and * represent significance levels of 1%, 5% and 10%

respectively

In order to further study the role of digital finance on urban ecological resilience, this study conducted a further regression analysis on the secondary indicators of digital finance on urban ecological resilience: state resilience, stress resilience and response resilience. After the joint hypothesis test (F test) and the Hausman test, the P value in the F test is 0.000***. The P value of Hausmann test was < 0.05, so the FE model was used in this study for subsequent regression analysis.

The regression results are shown in Table 7. It can be seen from the table that the significance P value is 0.000***, showing significance at the level and rejecting the null hypothesis, so the model is effective. At the same time, in the regression of state resilience, the coefficient of the digital finance index is positive and the P-value is 0.000, which is significant at 1%, indicating that digital finance has a significant promoting effect on state resilience. In the stress resilience regression, the coefficient of the digital finance index is negative and the P-value is 0.000, which is significant at 1%, indicating that digital finance has a significant inhibitory effect on stress resilience. In response resilience regression, the coefficient of the digital finance index is negative and the P-value is 0.000, which is significant at 1%, indicating that digital finance has a significant promoting effect on response resilience.

Table 7. Regression results of secondary variables of ecological resilience

Variable	Coefficient	Standard Error	t	F	Ecological Resilience Species
Digital finance index	0.024	0.003	4.942	F=12.332 P=0.000***	State toughness
Digital finance index	0.017	0.001	-6.472	F=91.339 P=0.000***	Pressure toughness
Digital finance index	0.009	0.002	8.181	F=107.549 P=0.000***	Response toughness

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively

5.2. Chain mediation Effect

Table 8. Coefficient of chain mediation effect model

	Ecological resilience （Y）	Technological innovation	Energy consumption	Ecological resilience （Y）
constant	-0.035	-5.786	3.207	-0.016
Digital finance index （X）	0.009	0.83	-0.292	0.007
Income level (control variable)	0.007	0.727	-0.256	0.005
Industrial structure (control variable)	-0.006	0.141	-0.041	-0.006
Open to the outside world (control variable)	0.007	-0.159	0.258	0.008
Population density (control variable)	0.007	1.026	-0.196	0.005
Technological innovation			-0.035	0.001
Energy consumption				-0.004
Sample size	405	405	405	405
R^2	0.47	0.834	0.579	0.489
adjust R^2	0.464	0.832	0.573	0.48
F	F(5，399)=70.861，P=0.000***	F(5，399)=401.292，P=0.000***	F(6，398)=91.229，P=0.000***	F(7，397)=54.312，P=0.000***

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively

Table 9. Summary results of mediation effect test process

Effect	Item	EFFECT SIZE	Standard Error	t	P	95% Lower bound of Confidence Interval	95% Upper limit of Confidence Interval
Direct effect	Digital finance index（X）=>Ecological resilience（Y）	0.007	0.001	4.965	0.000***	0.004	0.01
Indirect effect process	Digital finance index（X）=>Technological innovation	0.83	0.087	9.572	0.000***	0.659	1
	Digital finance index（X）=>Energy consumption	-0.292	0.06	-4.838	0.000***	-0.411	-0.173
	Technological innovation=>Energy consumption	0.035	0.031	-1.112	0.047**	0.027	0.097
	Technological innovation=>Ecological resilience（Y）	0.001	0.001	1.129	0.260	-0.001	0.002
	Energy consumption=>Ecological resilience（Y）	-0.004	0.001	-3.589	0.000***	-0.006	-0.002
Total effect	Digital finance index（X）=>Ecological resilience（Y）	0.009	0.001	7.155	0.000***	0.007	0.012

The direct effect of digital financial index (X) on ecological resilience (Y) is significant, indicating that the improvement of digital financial index has a positive promoting effect on ecological resilience when other factors are controlled, and this effect is highly statistically significant. The 95% confidence interval (0.004 to 0.01) further confirms the robustness of this positive relationship.

Further analysis of the indirect effect process shows that digital finance index (X) has a significant positive impact on technological innovation, indicating that the development of digital finance promotes technological innovation. However, the digital finance index has a significant negative impact on energy consumption, which means that the development of digital finance helps to reduce the impact of technological innovation on energy consumption is positive, indicating that technological innovation significantly reduces energy consumption.

The direct effect of technological innovation on ecological resilience is not significant, indicating that technological innovation itself has limited effect on ecological resilience.

It is worth noting that energy consumption has a negative impact on ecological resilience, suggesting that increased energy consumption reduces ecological resilience - a finding that underscores the importance of reducing energy consumption in improving ecological resilience.

Finally, the total effect of the digital financial index on ecological resilience is significant, and this effect is composed of both direct effects and indirect effects through energy consumption. This result not only confirms the direct impact of the digital finance index on sex, but also reveals the complex mechanisms by which it indirectly improves ecological resilience by reducing energy consumption.

Table 10. Indirect effect analysis

Item	Effect	Boot SE	BootLLC	BOOtULC	z	p
Digital finance index（X）=>Technological innovation=>Energy consumption=>Y	0.34	0.001	0.005	0.917	1.024	0.032**

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively

The estimated value of the effect of digital finance on ecological resilience is 0.34, which means that when digital finance increases by 1, the ecological resilience will increase by 0.34. Meanwhile, the standard of Bootstrap is mistakenly set to 0.001, which means that the estimated value of this effect has high stability. Meanwhile, Bootstrap (BootLLC to BOOtULC) does not contain 0. This suggests that the mediating effect is statistically significant.

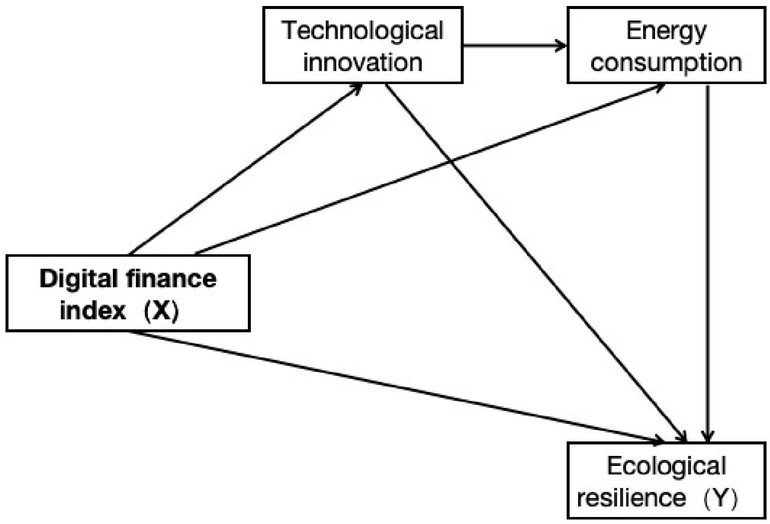

Figure 1. Mediating effect path

5.3. Effectiveness of Ecological Compensation Pilot Policy—DID Differential

In the Yangtze River Delta city cluster, we selected cities approved by The State Council, the People's Government, the Development and Reform Commission, the Ministry of Finance and the Ministry of Environment and Ecology in 2019 in Anhui Province, which took the lead in establishing the cross-provincial basin compensation mechanism, to carry out pilot work in five counties (cities and districts) as the experimental group, and other cities in the Yangtze River Delta as the control group. Mark 2019 as the time of the event. The survey samples are divided into two groups, one is the policy target, the city affected by the "ecological compensation pilot policy", and the other is the non-policy target. According to the relevant information of the experimental group and the control group before and after the policy, we first calculated the change amount of the ecological resilience of the experimental group before and after the policy implementation, and calculated the change amount of the same index of the control group before and after the policy implementation. Finally, the difference of the above two changes is calculated, and the "double difference" is obtained. DID was performed at the provincial level, and the results of the differential regression are shown in Table 11 below:

Table 11. The results of differential model regression

Variable	Coefficient	Standard Error	T-value	p-value	[0.025, 0.975] Confidence Interval
Treat	0.024	0.011	2.15	0.031	[0.0022, 0.0470]
Post	0.032	0.013	2.49	0.013	[0.0069, 0.0589]
Treat×Post	0.045	0.015	2.88	0.004	[0.0145, 0.0761]
Income level	0.02	0.003	5.39	0	[0.0130, 0.0280]
Industrial structure	-0.007	0.002	-3	0.003	[-0.0129, 0.0027]
Open to the outside world	-0.019	0.008	-2.23	0.026	[-0.0365, 0.0023]
Population density	0.005	0.002	2.16	0.03	[0.0005, 0.0100]
Constant term	-0.142	0.027	-5.19	0	[-0.1960, 0.0886]

R^2	0.684
adjust R^2	0.662
F-number	31.09
P value (F test)	0

From the regression results, the coefficient of the interaction term Treat×Post is 0.0453, which is significantly positive at the 1% level. This indicates that the pilot ecological environment compensation policy has a significant positive effect on the ecological resilience of urban agglomerations, and the ecological resilience of the pilot cities significantly increases by 4.53% after the implementation of the policy. That is, the pilot policy of ecological environment compensation policy is effective, and further tested hypothesis 4. After the implementation of the policy, the ecological toughness of the pilot cities has a more obvious improvement compared with the non-pilot cities, and this study believes that the pilot policy of ecological environment compensation policy guides the pilot cities to increase the investment in ecological environment protection through financial compensation and industrial support, which promotes ecological restoration and environmental governance, and then improves the ecological toughness.

As for the control variables, the coefficient of income level is significantly positive, which means that the increase of income level has a positive impact on ecological resilience, and economic development provides more resources and technical support for ecological protection. The coefficient of industrial structure is significantly negative, implying that the optimisation of industrial structure (e.g. reducing the proportion of high-pollution and high-energy-consumption industries) contributes to the enhancement of ecological resilience. The coefficient of openness to the outside world is significantly negative, which may be due to the fact that in the process of opening up, some cities over-pursued economic growth and neglected ecological protection, but with the further improvement of openness and the enhancement of environmental protection awareness, this negative impact may be gradually weakened. The coefficient of population density is significantly positive, indicating that moderate population agglomeration may promote the intensive use of resources and have a certain effect on ecological resilience.

The benchmark regressions above only ensure that DID is extracting the causal effect of policy if districts are sufficiently similar pre-policy, so we multiply the year dummy variable by the experimental group dummy variable to capture the difference between the two groups of districts in each year and thus account for the distance between the two groups of districts pre-policy. If parallel trends do exist between the two groups of regions, then it is expected that the regression results of those interaction terms will be insignificant before 2019, while significant results are presented after 2019.Methods of conducting parallel trend tests for DID models usually include t-tests, graphical methods, and interaction term regressions. Here, we conduct a t-test on the explanatory variable ecological resilience to prove the ‘parallel trend’ test by the significance of the results presented. t-tests before and after 2019 are shown in Table 12 below:

Table 12. Analysis of t-test results

Items	Control	Treated	Diff	t	p
ER(Before)	2.512	2.597	0.085	2.518	P = 0.062*
ER(After)	2.875	3.063	0.188	4.447	P = 0.000***

In the ER(Before)T test, the T-value was 2.518, which was significant at the significance level of 10%. This indicates that before the implementation of the policy, the mean ecological resilience of the treatment group and the control group has a certain degree of difference, but the significance level is relatively low, and the interference to the subsequent policy effect assessment is relatively small.

In the ER (After) T test, the mean value of ecological resilience in the control group was increased to 2.875, and that in the treatment group was increased to 3.063, with a difference of 0.188. The mean value of the treatment group was significantly higher than that of the control group, and the difference increased compared with that before the implementation of the policy. The T-value was 4.447, which was significant at the significance level of 1%. This showed that after the implementation of the policy, the mean difference of ecological resilience between the treatment group and the control group was highly significant.

From the data change trend before and after the implementation of the policy, the mean value of ecological resilience of both groups increased, and the mean value of the treatment group was always higher than that of the control group. The difference value increased significantly after the implementation of the policy, and the significance level of the T-test increased significantly. After controlling for other factors affecting ecological resilience, the significant differences between the treatment and control groups after policy implementation are likely to be caused by policy intervention. Since the mean difference between the two groups was small and significant before the implementation of the policy, and the difference increased significantly after the implementation, it can be preliminarily inferred that the policy has a positive effect on the improvement of ecological resilience in the treatment group.

Therefore, the null hypothesis is rejected in this paper. The T-test passes and DID can be used for evaluation.

6. Conclusions and Policy Recommendations

Digital finance has a positive promoting effect on improving the ecological resilience of the Yangtze River Delta urban agglomeration, which significantly promotes the ecological resilience of the urban agglomeration through its effects on state resilience, pressure resilience and response resilience. Technological innovation and energy consumption play a role as a chain intermediary, and the main path is that digital finance acts on technological innovation and then affects energy consumption, which further affects the ecological resilience of urban agglomerations. At the same time, this study discusses the effectiveness of the pilot ecological compensation policy. The research results show that after the implementation of the policy, the ecological resilience of the experimental group has been significantly improved, which further demonstrates the effectiveness of the pilot policy.

Based on the above conclusions, this paper puts forward the following policy recommendations.

First, promote the deep integration of digital finance and green technology innovation. The government has set up a special green finance fund to provide financing support to green technology projects through digital platforms to reduce the financing cost of green projects. At the same time, a green credit incentive mechanism has been introduced to encourage financial institutions to provide low-interest loans to green projects and promote the rapid development of green technologies. Preferential tax policies for green technology innovation should also be introduced to support enterprises to increase investment in green technology research and development, clean energy and environmental protection, and encourage technological innovation. Through these policies, the application and promotion of green technologies can be accelerated, and the transformation of the Yangtze River Delta urban agglomeration to low-carbon and sustainable development can be promoted.

Secondly, optimizing energy consumption management and improving energy efficiency are key. The government should increase investment in intelligent energy management systems, promote the construction of digital energy management platforms, and use big data and Internet of Things technology to monitor energy consumption in real time and optimize energy efficiency. At the same time, a green energy consumption subsidy policy has been introduced to encourage enterprises and residents to use renewable energy, especially in energy-intensive areas such as industry and transportation. In addition, through the introduction of digital technologies such as blockchain, improve the transparency and efficiency of energy transactions, promote the market-oriented trading of green energy, and reduce energy waste.

Third, continue to deepen and further optimize the ecological compensation policy to ensure effective protection of the ecological environment. The government should dynamically adjust the ecological compensation standard according to the ecological environment status of different regions and the development level of urban agglomerations, and evaluate the implementation effect of the policy through big data analysis and timely optimization. Further through the blockchain technology to ensure the transparent flow of compensation funds to avoid the retention or waste of funds. On this basis, we can promote the establishment of cross-regional ecological compensation mechanisms, encourage cooperation between different cities, and realize the sharing and complementation of ecological protection resources. We will guide social capital to participate in ecological compensation projects and provide more financial support for ecological protection.

Fourth, strengthen policy supervision and implementation mechanisms to ensure that all policy measures take effect. The government should establish a real-time regulatory system through digital technology to effectively monitor the green financial market, ecological projects and energy consumption to prevent the waste of resources and abuse of funds. Especially in the field of digital finance, it is necessary to establish a strict market supervision mechanism to ensure the transparency and fairness of policies. At the same time, through the cross-departmental coordination mechanism, the resources of all parties are integrated to ensure the coordinated implementation of various policies, avoid repetition and conflicts in policy implementation, and improve the comprehensive benefits of policies.

Finally, the government should encourage the public to actively participate in green finance and ecological construction, and enhance the awareness of green environmental protection in the whole society. Investment vehicles such as green bonds and environmental funds can be promoted through digital platforms to make it easier for public and private investors to participate in green projects, thus providing more financial support for green transformation. The government should also strengthen green finance education, popularize green investment knowledge to the public through online platforms and social activities, and stimulate more social capital to invest in environmental protection and green technology, so as to provide sustainable impetus for ecological construction.

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Thus, the ecological resilience of the Yangtze River Delta urban agglomeration can be further effectively improved, its ability to cope with external shocks such as climate change and resource shortage can be enhanced, and sustainable economic development in the region can be promoted. At the same time, promoting green transformation and sustainable development across the country.

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