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An Informatics-Based Analysis of the Nonlinear Impact of Green Finance on Digital Economy Development: Evidence from Chinese Provinces

Hongwei Li [1], Chunmei Huang[2], Yuzhong Yao [2]

[1] International College of Krirk University; Bangkok, 10220, Thailand

[2] Lampang Inter-Tech College; Lampang,52000, Thailand

13910698287@139.com, 2274382661@qq.com, 1458723664@qq.com (corresponding author)

Abstract. This study explores the nonlinear relationship between green finance and digital economy development in China from an informatics and service-science perspective. Using panel data from 30 provinces between 2000 and 2023, the research constructs composite indices of green finance and digital economy through the entropy weight method and employs threshold regression and spatial Durbin models to analyze their interactions. The results reveal a significant inverted U-shaped nonlinear effect of green finance on the digital economy, suggesting that while green finance initially enhances digital economic growth through optimized resource allocation and green innovation, its marginal benefits diminish as expansion intensifies. Moreover, the study identifies a negative spatial spillover effect, indicating competitive crowding-out of digital resources among neighboring provinces. These findings highlight the stage-dependent and spatially heterogeneous characteristics of green finance's influence on the digital economy. By framing green finance as an informatics-based financial service system, the study provides empirical evidence and decision-support implications for enhancing regional coordination, improving digital governance mechanisms, and promoting the sustainable and intelligent growth of China's digital economy.

Keywords: Green Finance; Digital Economy; Threshold Effect; Nonlinear Impact; Spatial Durbin Model Informatics-based Governance; Spatial Spillover

1. Introduction

Against the dual backdrop of global climate change and technological revolution, China is actively advancing its strategic objectives of carbon peaking and carbon neutrality (the "dual-carbon" targets) and has identified green and low-carbon development as a crucial pathway for achieving high-quality growth. Simultaneously, the ongoing deepening of the "Digital China" strategy signifies an accelerated systemic process through which digital technologies are reshaping traditional industries and transforming the mechanisms of economic and social operations. The synergistic evolution of these two strategies constitutes a "dual-engine" driving China's high-quality economic transformation, imposing new requirements on the allocation of financial resources and the orientation of macroeconomic policies.

In the course of implementing the dual-carbon strategy, green finance has been entrusted with the essential function of guiding resources toward green and low-carbon sectors while incentivizing investments in clean energy and environmentally friendly technologies. The gradual improvement of financial instruments, including green credit, green bonds, green insurance, and carbon finance, has become a key support mechanism for restructuring factor markets and constructing a green production system.

Meanwhile, the Digital China strategy emphasizes the empowerment of the economy through digital technologies, promoting the digital transformation of economic systems, government governance, and social services. Particularly in the post-pandemic era, the accelerated construction of digital infrastructure, the enhancement of data element circulation mechanisms, and the scenario-based deployment of artificial intelligence and the Internet of Things have facilitated the emergence and expansion of new forms of digital economy. However, the rapid growth of the digital economy has also introduced new green challenges, such as increased complexity in energy consumption structures and concentrated energy demands in data centers, thereby creating a practical need for green finance to effectively support digital economic development.

It is noteworthy that under the current context of "dual-wheel" advancement in green and digital transformation, the intersection between these two domains is expanding, exemplified by the rapid development of green digital technologies, green information infrastructure, and green intelligent manufacturing. Consequently, green finance not only plays a role in greening traditional industries but also increasingly permeates the capital formation and technological evolution of the digital economy, prompting both theoretical and empirical discussions on whether green finance can effectively guide the high-quality development of the digital economy.

Therefore, within the overarching context of the coordinated promotion of the dual-carbon and Digital China strategies, clarifying the pathways through which green finance affects digital economic development holds substantial theoretical significance and policy implications. Guided by this logic, the present study systematically analyzes, using provincial panel data, how green finance influences the development level of China's digital economy and further examines whether such effects exhibit significant nonlinearity and regional heterogeneity.

2. Literature Review

2.1. Concept of Green Finance

The origin of green finance can be traced back to the United States' Superfund Act and the well-known "Love Canal" pollution incident, which marked a growing awareness of environmental risks and the need for financial mechanisms to address them. With the increasing global recognition of sustainable development, the concept of green finance emerged as a financial innovation aimed at effectively addressing environmental challenges. According to Salazar (1998) and Cowan (1999), green finance refers to the use of financial instruments by governments and financial institutions to promote ecological protection and foster a green, low-carbon, and sustainable economy. Similarly, Wang and Wang (2018) argue that green finance is a type of financial tool embedded within the broader framework of environmental policy. Wen et al. (2022) and Chen et al. (2022) further suggest that, although definitions of green finance vary across studies, they converge on the view that it encompasses financial services supporting economic sustainability based on environmental protection, efficient utilization of natural resources, and mitigation of climate change.

At the 2006 G20 Summit, during China's presidency, the Chinese government officially articulated the national definition of green finance. It emphasized that green finance refers to a comprehensive financial service system—including investment, financing, project operation, and risk management—targeting projects related to environmental protection, energy conservation, emission reduction, and climate change mitigation, thereby promoting sustainable development. This definition has been widely acknowledged and adopted as the authoritative interpretation of green finance in China. The present study builds upon this conceptual foundation to conduct an in-depth analysis of green finance.

Green finance primarily consists of green credit, green securities, green insurance, and green investment (Yu & Fan, 2022). With the growing global focus on carbon emissions, environmental protection, and sustainable development, scholars have increasingly incorporated carbon finance—particularly carbon emission intensity—into the measurement framework of green finance, forming a widely recognized index system (Liu et al., 2021; Zhou & Li, 2024). Lin and Xiao (2023) included the "green support" indicator in their evaluation system, further broadening the scope of green finance assessment. More recently, Xue and Kan (2024) as well as Li and Liu (2024) have extended the framework by including green funds as a key component of green finance measurement.

Overall, as the research on green finance evolves, the measurement framework has become progressively refined, allowing for a more comprehensive and scientifically robust green finance composite index. Guided by prior empirical studies, the present research adopts seven specific indicators—green credit, green securities, green insurance, green investment, green funds, green support, and carbon finance—to construct a comprehensive measure of green finance.

2.2. Concept of Digital Economy

As a rapidly emerging socio-economic phenomenon, the digital economy has become one of the central research topics in contemporary economics and management science, encompassing its conceptual connotations, structural characteristics, governance challenges, and developmental impacts. Yang (2025) posits that the essence of the digital economy lies in the utilization of digital knowledge and information as key factors of production, employing modern information networks as the primary vehicle and leveraging the extensive application of information technology to stimulate economic growth, enhance efficiency, and optimize industrial structures. The digital economy not only encompasses transactions of goods and services facilitated by digital technologies but also includes a wide array of cross-industry and cross-sectoral economic activities enabled by digital connectivity. Supported by diverse technological infrastructures—such as the Internet, mobile communications, big data, and information and communication technologies (ICT)—it constitutes a highly integrated economic ecosystem connecting individuals, enterprises, objects, data, and operations (Javaid et al., 2024).

Huang, Wang, and colleagues (2023) further emphasize that the digital economy represents an economic paradigm underpinned by digital computing and algorithmic technologies, covering diverse domains such as e-commerce, digital services, online education, the sharing economy, and other forms of production and consumption conducted via digital platforms. From the perspective of developmental drivers, Xu et al. (2024) conceptualize the digital economy as a technology-driven economic form in which data resources serve as the core production factor, modern information networks function as essential infrastructure, and ICT acts as the technological foundation. Through the deep integration of digital technologies with the real economy, the digital economy achieves transformations in efficiency, power, and structure, thereby fostering high-quality economic development. Meanwhile, Javaid et al. (2024) highlights the distinctive nature of the digital economy in contrast to traditional economic forms, emphasizing its deep reliance on digital technologies and online transaction mechanisms, which enable technological innovation and data-driven reconfiguration of conventional industries.

Synthesizing these scholarly perspectives, the digital economy is widely regarded as the outcome of profound integration between information technologies and economic activities. Through digital technologies such as the Internet, artificial intelligence (AI), and big data, it fosters innovation in both platforms and infrastructure, playing a crucial role in enhancing productivity, reducing transaction costs, dismantling trade barriers, and promoting sustainable development.

Xu and Tao (2022) further assert that within the digital economy system, data has transcended its traditional role as a mere carrier of information to become a novel production factor with resource attributes. It now permeates all stages of production, circulation, and consumption, serving as a fundamental driver for resource reallocation and structural transformation. The operation of the digital economy relies on modern information network infrastructure — such as the Internet, mobile communications, and the Internet of Things (IoT)—which collectively form the foundation of digital economic activity. Its development is inseparable from the ICT support system represented by the Internet, big data, cloud computing, artificial intelligence, and 5G technologies (Yang, 2025). This technology-driven mechanism endows the digital economy with unique innovative vitality and developmental dynamism, allowing it to emerge not only as an independent economic domain but also as a catalyst for the digital transformation and upgrading of traditional industries. Through this dual integration of industrial digitalization and digital industrialization (Fu, 2022), the digital economy empowers the real economy, generates new growth momentum and competitive advantages, and serves as a critical driving force in the continuous evolution of the modern economic system.

2.3. The Impact of Green Finance on the Digital Economy

As two pivotal pillars underpinning China's transformation from traditional to new economic growth drivers and its pursuit of sustainable development, green finance and the digital economy have increasingly become focal points of scholarly and policy discourse (Cui & Ma, 2023). The theoretical foundation for examining the influence of green finance on the digital economy is rooted in sustainable development theory, financial innovation theory, and green growth theory. From the perspective of sustainable development, the rapid expansion of the digital economy has contributed to enhanced efficiency and industrial upgrading, yet it also entails significant energy consumption and environmental pressure. For instance, the high energy intensity of data centers and blockchain mining activities has, to some extent, rendered the digital economy a new driver of carbon emissions (Chen & Shen, 2022). Consequently, green finance—through mechanisms such as environmental risk pricing and green credit policies—plays a crucial role in mitigating the environmental externalities generated by digital economic growth.

Within the framework of financial innovation theory, green finance advances institutional and financial instrument innovation, thereby internalizing environmental costs within financial market operations. By embedding green constraints into the logic of financial systems, instruments such as green bonds, green funds, and carbon trading markets have emerged as critical bridges linking capital with low-carbon technologies, fostering the greening and sustainable transformation of the digital industry (Liu & He, 2021).

From the perspective of mechanism, the impact of green finance on the digital economy manifests across multiple dimensions. First, at the level of capital support, green credit and investment mechanisms provide essential financial backing for the green transformation of the digital economy. Green financial policies guide capital flows toward low-carbon digital industries through differentiated interest rates, fiscal subsidies, and green rating systems, thereby reducing the financing costs associated with renewable energy utilization, intelligent manufacturing, and green technology applications among digital enterprises (Peng et al., 2024). Notably, since the implementation of green finance pilot policies, small and medium-sized innovative enterprises within the digital economy have gained expanded access to financing opportunities, with optimized capital structures furnishing a solid foundation for sustained innovation (Han, 2020).

Second, from the technological innovation perspective, green finance stimulates digital enterprises to increase investment in energy-saving technologies, intelligent equipment, and low-carbon algorithms through incentive mechanisms. For example, green funds have gradually extended their investment focus from traditional environmental protection industries to emerging green digital sectors, including smart energy management systems and blockchain-based carbon accounting platforms (Zhang & Chen, 2022). This innovation-driven capital orientation fosters technological diffusion and knowledge spillover effects within the digital economy.

Third, from the perspective of industrial coordination, green finance promotes a dynamic interconnection among capital, technology, and industry through investments in green industrial chains and innovations in supply chain finance. The integration of green credit with digital technologies has facilitated the emergence of "green supply chain finance" models, enhancing resource allocation efficiency across industries (Cao & Zhang, 2025). Moreover, the development of digital financial infrastructure has further reduced transaction costs for green projects, rendering the supportive role of green finance in the digital economy more universal, efficient, and sustainable.

From the perspective of existing empirical studies, the works of Xie and Zhou (2023), Cao and Zhang (2025), and Su et al. (2025) all confirm that green finance exerts a significant positive influence on the green development of the digital economy. Specifically, Su et al. (2025) employed a 10-year provincial panel dataset covering the period from 2015 to 2024, Cao and Zhang (2025) used a 12-year dataset spanning from 2011 to 2022, while Xie and Zhou (2023) utilized a 7-year provincial panel dataset from 2013 to 2019. Building upon these prior works, the present study adopts a longer temporal span—provincial panel data covering 24 years from 2000 to 2023—to examine the overall trends of green finance's influence on the digital economy, thereby providing a more comprehensive verification and extension of the conclusions reached by previous scholars.

Su et al. (2025), in their paper The Impact of Green Finance on the Digital Economy: Promotion or Inhibition? —Empirical Evidence from China, argued that green finance has an inverted U-shaped nonlinear effect on the digital economy, although they did not provide empirical validation within that study. Similarly, Cao and Zhang (2025), employing a single-threshold panel model, found that green finance exhibits a nonlinear single-threshold effect on the digital economy. Xie and Zhou (2023), using a comparable single-threshold panel framework, also identified a significant single-threshold effect, concluding that green finance exerts an inverted U-shaped nonlinear influence on the digital economy. On the basis of these findings, the present study seeks to further validate this nonlinear relationship by incorporating the squared term of green finance into the baseline panel regression model. Through analyzing the sign and significance of the estimated coefficient for the squared term, this study empirically tests whether the inverted U-shaped nonlinear influence of green finance on the digital economy holds over an extended temporal horizon.

Furthermore, studies by Su et al. (2025) and Xie and Zhou (2023) have demonstrated notable regional disparities in the impact of green finance on the development of the digital economy. These findings suggest that the level of influence exerted by green finance varies significantly across regions. However, none of these studies have further explored whether green finance contributes to the regional equilibrium and coordinated development of the digital economy. Based on the theory of regional balanced development, the present study applies a Spatial Durbin Model (SDM) to examine whether green finance generates significant regional spillover effects on the digital economy, and whether such spatial effects exhibit nonlinear characteristics. If nonlinearities are indeed present, the study aims to identify their specific functional forms and mechanisms.

To date, a review of the CNKI database reveals a scarcity of research that systematically investigates the spatial convergence and spillover effects of green finance on the digital economy, particularly from a nonlinear perspective. Accordingly, this study focuses on uncovering the nonlinear impact patterns of green finance on the digital economy, as well as its spatial convergence and spillover effects. This emphasis constitutes one of the principal innovations and contributions of the present research.

3. Research Methodology

3.1. Variable Definition and Measurement

1)Dependent Variable

The dependent variable in this study is the digital economy (DE). Wang et al. (2021) comprehensively conceptualized the digital economy by considering its conditions, applications, and environment, and constructed a digital economy indicator system from four dimensions: digital economy development carriers, digital industrialization, industrial digitalization, and the digital economy development environment. This indicator system comprises 30 specific tertiary indicators, providing a comprehensive reflection of the connotation of the digital economy. It has been widely adopted in prior research, and this study also employs this framework to measure the development level of the digital economy.

Table 1.Indicator System for Measuring the Digital Economy

Primary Indicator	Secondary Indicator	Secondary Indicator
Digital Economy Development Carriers	Conventional Infrastructure	Number of Internet Broadband Access Ports
		Number of Internet Broadband Subscribers
		Number of Domain Names per 1,000 People
		Number of Websites per 1,000 People
	Emerging Digital Infrastructure	Fixed Investment in the Electronic Information Industry
		Number of Mobile Telephone Base Stations
		Number of IPv4/IPv6 Addresses
Digital Industrialization	Industry Scale	Total Telecom Business Volume
		Software Product Revenue
		Information Service Revenue
	Industry Diversity	Number of Listed ICT Companies
		Number of Top 100 Internet Companies
		Number of Manufacturing Enterprises in the Electronic Information Industry
Industrial Digitization	Agricultural Digitization	Proportion of Administrative Villages with Broadband Access
		Rural Broadband Users
		E-commerce Revenue of Agricultural Products
	Industrial Digitization	Proportion of Internet Usage in Industrial Applications
		Number of Computers per 100 Employees in Industrial Enterprises
		Integration of Informatization and Industrialization Index
		E-commerce Transaction Volume of Industrial Enterprises

	Service Sector Digitization	Proportion of Enterprises Engaged in E-commerce Transactions
		E-commerce Transaction Volume
		Investment in Internet-related Service Industries
		Digital Inclusive Finance Index
Digital Economy Development Environment	Governance Environment	Number of Government Agencies' Microblogs
		Government E-Government Application Index
		Number of Digital Intellectual Property Contracts Executed
	Innovation Environment	R&D Expenditure
		Proportion of Digital Knowledge-based Talent Employed
		Number of Employees in Software R&D

2) Explanatory Variable

The explanatory variable in this study is green finance (GF). Regarding the specific measurement framework for green finance, this study builds upon the measurement indicators proposed by scholars such as Bo and Fan (2022), Lin and Xiao (2023), and Xue and Kan (2024), adapting and constructing a green finance indicator system tailored to the context of the present research (see Table 2).

Table 2. indicator system of green finance

Primary Indicator	Secondary Indicator	Operational Definition of Secondary Indicator	
Green Finance	Green Credit	Ratio of Environmental Project Loans to Total Loans	Environmental Project Loan Amount /Total Loan Amount
	Green Investment	Ratio of Environmental Pollution Control Investment to GDP	Environmental Pollution Control Investment / GDP.
	Green Insurance	Extent of Promotion of Environmental Pollution Liability Insurance	Environmental Pollution Liability Insurance Revenue / Total Premium Income
	Green Bonds	Degree of Development of Green Bonds	Total Issued Green Bonds / Total Bond Issuance
	Green Support	Ratio of Fiscal Environmental Protection Expenditure to General Budget Expenditure	Fiscal Environmental Protection Expenditure / General Budget Expenditure
	Green Funds	Ratio of Green Fund Market Value to Total Fund Market Value	Total Market Value of Green Funds / Total Market Value of All Funds
	Carbon Finance	Carbon Emission Intensity	Carbon Emissions / GDP

3)Control Variables

Considering the significant impact of green finance on the digital economy, as well as other factors that may influence its development, this study includes several control variables: environmental regulation (hjgz), fiscal support intensity (czzc), and consumption level (xfsp), urbanization level (czhl). These variables are selected based on their potential effects on the digital economy. Detailed definitions and descriptions of these variables are presented in Table 3.

Table 1. Control Variables

Control Variable	Operational Definition
Environmental regulation (hjgz)	Industrial Pollution Control Investment Completed / Industrial Added Value
Government Support (czzc)	Fiscal Expenditure / GDP
Consumption level (xfsp)	GDP per Capita
Urbanization level (czhl)	Urban Population / Total Population

3.2. Model Design

1)Threshold Regression Mode

Based on the research hypotheses, this study first employs a panel threshold regression model to examine whether the impact of green finance on the digital economy exhibits nonlinear threshold effects. The threshold regression model is constructed as follows:

$$\mathrm{lnde}=\beta_0+\beta_1\mathrm{lngf}\cdot I(\mathrm{lngf}\leq\delta_1)+\beta_2\mathrm{lngf}\cdot I(\delta_1<\mathrm{lngf}\leq\delta_2)+\beta_3\mathrm{lngf}\cdot I(\delta_1<\mathrm{lngf})+\sum_{j=1}^{5}\gamma_j\,\mathrm{control}_{j,i,t}+\varepsilon_{i,t} \quad (1)$$

Here, $I(.)$ denotes the indicator function, which takes a value of 1 if the condition inside the parentheses is satisfied, and 0 otherwise; δ_1 and δ_2 represents the threshold value of green finance; β_i（i=1、2、3）are the regression coefficients corresponding to different intervals of green finance. ; $\mathrm{control}_{j,i,t}$ denotes the set of control variables.

2)Baseline Panel Regression Model

The impact of green finance on the digital economy exhibits a significant threshold effect, indicating a nonlinear relationship. To further characterize the specific form and pattern of this nonlinear effect, this study employs a baseline panel regression model. In the modeling process, the squared term of green finance (lngf2) is introduced to capture the nonlinear influence of green finance. The model is specified as follows to examine this relationship:

$$\mathrm{lnde}_{i,t}=\gamma+\gamma_1\mathrm{lngf}_{i,t}+\gamma_2\mathrm{lngf2}_{i,t}+\sum_{j=3}^{7}\gamma_j\,\mathrm{control}_{j,i,t}+u_i+\mu_i+\varepsilon_{i,t} \quad (2)$$

Where, $\mathrm{lngf}_{i,t}$ represents the level of green finance in province i at year t , $\mathrm{lngf2}_{i,t}$ denotes the squared term of green finance for province i at year t, lnde is the level of digital economy in province i at year t, $\mathrm{control}_{j,i,t}$ represents the value of the j-th control variable for province i at year$_t$; , u_i denotes the individual fixed effect, μ_i denotes the random effect, $\varepsilon_{i,t}$ is the error term.

3) Spatial Econometric Model

To systematically examine the spatial effects of green finance on the digital economy, this study adopts a **spatial econometric framework**, specifically a spatial Durbin model (SDM). This model allows for the simultaneous estimation of direct effects on a province's own digital economy and indirect spillover effects on neighboring provinces, capturing potential spatial interactions in green finance development. The model can be expressed as follows:

$$\mathrm{lnde}_{i,t}=\rho W\mathrm{lnde}_{i,t}+\gamma_1\mathrm{lngf}_{i,t}+\gamma_2\mathrm{lngf2}_{i,t}+\sum_{j=3}^{6}\gamma_j\,\mathrm{control}_{j,i,t}$$
$$+\theta_1 W\mathrm{lngf}_{i,t}+\theta_2 W\mathrm{lngf2}_{i,t}+\sum_{j=3}^{6}\theta_j\,W\mathrm{control}_{j,i,t}+u_i+\mu_i+\varepsilon_{i,t} \quad (3)$$

Where, W represents the spatial weight matrix, ρ and θ_i (i=1 to 6) are spatial autoregressive coefficients capturing the spillover effects of the dependent and explanatory variables, respectively; u_i and μ_i denote province and time fixed effects; $\varepsilon_{i,t}$ is the error term.

This modeling approach enables the decomposition of total effects into direct effects (impact on the local province) and indirect spatial spillover effects (impact on neighboring provinces), providing a nuanced understanding of how green finance influences the digital economy both locally and regionally.

3.3. Data Collection and Composite Index Construction

Considering the completeness and accessibility of the specific indicators, this study collects data for 30 provincial-level administrative regions in China (provinces, municipalities, and autonomous regions), excluding Tibet, Taiwan, Macau, and Hong Kong, covering the period from 2000 to 2023. For the indicators within the digital economy index system, the data are primarily sourced from the official website of the National Bureau of Statistics of China (NBS), the China Academy of Information and Communications Technology (CAICT), reports and publications from the Ministry of Industry and Information Technology (MIIT), provincial statistical yearbooks, annual *China Digital Economy Development Reports*, the *China Statistical Yearbook*, the *China Information Yearbook*, and the *China Information Industry Yearbook*.

For the green finance index system, data on green credit, green bonds, and green funds are obtained from the *China Financial Statistical Yearbook*, green investment data from the *China Environmental Statistical Yearbook*, green insurance from the *China Insurance Yearbook*, and general green support from the *China Statistical Yearbook*. Carbon emissions data are sourced from the *CEADs China Carbon Accounting Database*. Control variable data are obtained from the *China Statistical Yearbook*, the *China Environmental Statistical Yearbook*, and the China National Research Data Service Platform (CNRDS).

The composite index for green finance (hereinafter “Green Finance”) is constructed using the entropy weighting method, following Shi (2023). Similarly, the composite index for the digital economy (hereinafter “Digital Economy”) is constructed using the entropy weighting method based on the methodology of Wang et al. (2021). To enhance the stability of the time series data, all variables are log-transformed prior to empirical analysis.

4. Results and Discussions

4.1. Descriptive Statistics

As shown in Table 4, there exists a considerable gap between the maximum and minimum values of green finance and the digital economy in China, reflecting the inter-provincial disparities in the development of both green finance and the digital economy. Similarly, the development levels of environmental regulation, government support, urbanization rate, and consumption also exhibit regional differences, indicating that significant disparities persist across provinces in terms of digital economy development.

Table 4. Descriptive Statistics

Variable Name	Definition	Mean	Standard Deviation	Minimum	Median	Maximum
lnde	Digital Economy	-1.58	0.74	-4.46	-1.51	-0.06
lngf	Green Finance	-1.39	1.03	-5.89	-1.00	-0.05
lnhjgz	Environmental Regulation	-5.88	0.95	-9.68	-5.75	-3.47
lnczzc	Government Support	-1.61	0.43	-2.67	-1.61	-0.28
lnczhl	Urbanization Rate	-0.69	0.34	-1.91	-0.64	-0.11
lnxfsp	Consumption Level	-1.00	0.18	-1.72	-0.99	-0.49

4.2. Correlation Analysis

The correlation analysis indicates that, during the period 2000–2023, the green finance index and the digital economy index across 30 provincial-level administrative regions in China (excluding Tibet, Hong Kong, Macau, and Taiwan) exhibit a significant positive relationship, with higher coefficients reflecting a stronger association between the two variables. Meanwhile, all other control variables also demonstrate statistically significant correlations with the digital economy index.

Table 5. Correlation Analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) lnde	1.0000					
(2) lngf	0.7826***	1.0000				
(3) lnhjgz	-0.5737***	-0.4870***	1.0000			
(4) lnczzc	-0.1112***	-0.4337***	0.0502	1.0000		
(5) lnczhl	0.7132***	0.4589***	-0.4297***	0.1766***	1.0000	
(6) lnxfsp	0.3606***	0.4387***	-0.1104***	-0.1085***	0.2610***	1.0000

*** *p<0.01*, ** *p<0.05*, * *p<0.1*

4.3. Threshold Model Analysis of Green Finance on the Digital Economy

To investigate the potential nonlinear impact of green finance on the digital economy, a triple-threshold panel regression model was established, with the digital economy as the dependent variable, relevant control variables as explanatory variables, and green finance as the threshold variable. The threshold effect of green finance was then tested. The results indicate that, at the 5% significance level, the single-threshold effect is statistically significant. Further calculations yield a threshold value of -3.3574 under the single-threshold specification.

Table 6. Bootstrap Test Results for the Threshold Effect of Green Finance

Threshold	MSE	Fstat	Prob	Crit10	Crit5	Crit1
Single	0.0377	50.66	0.02	28.4321	32.1323	61.4637
Double	0.0367	19.36	0.18	32.3121	38.5526	58.6195
Triple	0.0361	12.85	0.3333	26.4523	33.6651	49.3197

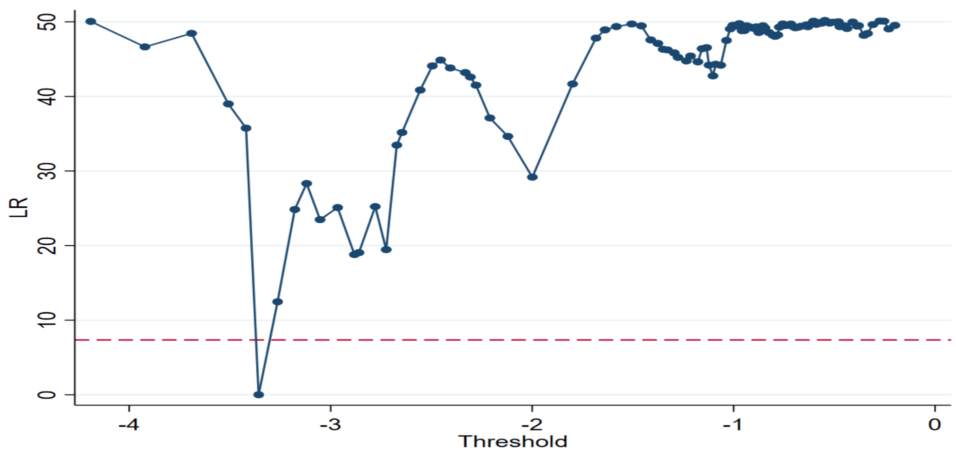

Fig.1: Estimated Threshold Values of Green Finance

From the regression outcomes, when the level of green finance is below the threshold (lngf < -3.3574), the coefficient of green finance on the digital economy is 0.383 ($t = 12.550$, $p < 0.001$), which is significantly positive, indicating that green finance exerts a strong promoting effect during its initial stage. Conversely, when green finance exceeds the threshold (lngf > -3.3574), the coefficient decreases to 0.296 ($t = 7.850$, $p < 0.001$), suggesting the presence of a nonlinear relationship between green finance and digital economy development.

These findings provide empirical support for the inverted-U nonlinear pattern previously proposed by Cao and Zhang (2025) and Xie and Zhou (2023), confirming that while green finance initially stimulates digital economic growth, its marginal effect diminishes as the level of green finance further increases. This highlights the importance of considering nonlinear threshold effects in policy formulation aimed at leveraging green finance to foster high-quality digital economy development.

Table 7. Estimated Coefficients of Green Finance in the Threshold Regression Model

lnde	Coefficient	Std.	err.	t	P>|t|	
lnhjgz	-0.077	0.011	-6.980	0.000	-0.099	
lnczzc	0.684	0.047	14.590	0.000	0.592	
lnczhl	0.599	0.050	11.990	0.000	0.501	
lnxfsp	-0.172	0.062	-2.790	0.005	-0.293	
lngf<-3.3574	0.383	0.031	12.550	0.000	0.323	
lngf>-3.3574	0.296	0.038	7.850	0.000	0.222	
_cons	-0.256	0.100	-2.550	0.011	-0.452	

4.4. Analysis of the Impact of Green Finance on the Digital Economy Using Static Panel Models

Based on the threshold model analysis in Section 4.2, it is evident that green finance exerts a nonlinear influence on the digital economy. To further investigate the specific pattern of this nonlinear effect, this section introduces the squared term of green finance ($lngf^2$) into a static panel regression framework. Regression models were constructed with green finance as the independent variable and the digital economy as the dependent variable. Specifically, Model (1) reports the results of the pooled regression, Model (2) presents the random effects panel regression results, and Model (3) reports the fixed effects panel regression results.

A Hausman test was conducted to compare the random effects and fixed effects models. The test yielded $\chi^2(7) = 30.21$, Prob > $\chi^2 = 0.0001$. The p-value is less than 0.05, indicating significant differences between the coefficients of the fixed effects and random effects models. Therefore, the fixed effects model is considered more appropriate for capturing the relationship between green finance and the digital economy.

Based on Model (3), green finance exhibits a significant inverted U-shaped nonlinear effect on the digital economy. Specifically, the coefficient of green finance is 0.2125 ($p < 0.01$), while the coefficient of its squared term is -0.0401 ($p < 0.01$).

Overall, from Model (1) to Model (3), green finance consistently shows a significant positive effect on the digital economy at the 1% significance level, and the squared term is consistently negative and significant. These results confirm the robustness of the inverted U-shaped nonlinear impact of green finance on digital economic development.

Table 8. Regression Estimates of the Impact of Green Finance on the Digital Economy

	Pooled OLS Model	Random Effects Model	Fixed Effects Model
	lnde	lnde	lnde
lngf	0.3114***	0.3593***	0.2125***
	(5.7813)	(6.2058)	(3.1023)
lngf2	-0.0245**	-0.0244***	-0.0401***
	(-2.1009)	(-2.6699)	(-4.0718)
lnhjgz	-0.1097***	-0.0717***	-0.0770***
	(-6.7484)	(-6.1504)	(-6.6274)
lnczzc	0.1204***	0.5894***	0.7139***
	(3.1675)	(13.5227)	(14.2781)
lnczhl	0.8341***	0.5955***	0.5891***
	(16.7611)	(11.7027)	(11.4703)
lnxfsp	0.0161	-0.1529**	-0.1749***
	(0.2003)	(-2.4125)	(-2.7744)
_cons	-0.9284***	-0.2158*	-0.2301**
	(-6.2376)	(-1.8262)	(-2.1593)
adj. R^2	0.789		0.832

This inverted U-shaped impact mechanism reflects that green finance operates within an "optimal development range" for the digital economy. At the early stages of development, green finance can inject growth momentum into the digital economy by directing green credit, promoting investment in green technologies, and strengthening green governance. However, in regions with high levels of green finance, overly rapid expansion may lead to resource misallocation, “greenwashing,” and regulatory arbitrage, ultimately constraining digital technology innovation.

4.5. Spatial Durbin Model Analysis of the Impact of Green Finance on the Digital Economy

Further, from a spatial perspective, this study examines whether green finance exerts spatial effects on the digital economy and whether such effects exhibit nonlinearity. Based on this, spatial econometric models are constructed using both the contiguity-based and geographic distance-based weight matrices to investigate the spatial effect patterns of green finance on the digital economy.

First, the global Moran’s I is computed for the digital economy, green finance, and its squared term under both weight matrices. If the Moran’s I indicates significant spatial autocorrelation for these variables, LM tests based on a mixed model are employed to examine whether the residuals of the digital economy in the mixed model exhibit significant spatial error and spatial lag effects. If neither effect can be ruled out, a Spatial Durbin Model (SDM) is specified with the digital economy as the dependent variable and green finance and its squared term as explanatory variables. Subsequently, a Hausman test is conducted to determine whether a random effects or fixed effects specification is more appropriate. If the fixed effects model is preferred, a WALD test is further conducted to assess whether the SDM can be simplified to a Spatial Error Model (SEM) or a Spatial Lag Model (SAR). The final spatial econometric model thus determined is then used to analyze the spatial effect patterns of green finance on the digital economy.

1) Test for Spatial Autocorrelation

This study employs the global Moran’s I to examine the spatial autocorrelation of each variable. The results generated by STATA 17 indicate that, whether using the geographic distance matrix or the contiguity-based adjacency matrix, the global Moran’s I of all variables is statistically significant at the 1% level. This suggests that all variables exhibit significant spatial correlation, justifying the use of spatial econometric models to further investigate the interrelationships among the variables.

Table 9. Global Moran’s I Test for Spatial Autocorrelation under Different Weight Matrices

Types of Spatial Weight Matrices	variable	I	E(I)	sd(I)	z	p-value*
Geographic Adjacency Matrix	lnde	0.64	-0.001	0.027	23.771	0.000
	lngf	0.49	-0.001	0.027	18.217	0.000
	lngf2	0.422	-0.001	0.027	15.75	0.000
	lnhjgz	0.526	-0.001	0.027	19.543	0.000
	lnczzc	0.623	-0.001	0.027	23.142	0.000
	lnczhl	0.639	-0.001	0.027	23.732	0.000
	lnxfsp	0.355	-0.001	0.027	13.22	0.000
GeographicDistance Matrix	lnde	0.44	-0.001	0.012	36.333	0.000
	lngf	0.196	-0.001	0.012	16.274	0.000
	lngf2	0.167	-0.001	0.012	13.934	0.000
	lnhjgz	0.458	-0.001	0.012	37.776	0.000
	lnczzc	0.374	-0.001	0.012	30.907	0.000
	lnczhl	0.468	-0.001	0.012	38.662	0.000
	lnxfsp	0.204	-0.001	0.012	16.908	0.000

2）Diagnostic Tests for Establishing the Spatial Durbin Model

In this study, diagnostic tests including the Lagrange Multiplier (LM) test, Wald test, and Hausman test were sequentially conducted under two types of spatial weight matrices to select the optimal spatial econometric model for analysis (see Table 10). The results indicate that when using the geographic contiguity matrix as the spatial weight matrix, robust LM tests reject the null hypothesis at the 1% significance level, suggesting the presence of significant spatial error and spatial lag effects. This implies that the Spatial Durbin Model (SDM) should be considered as the primary modeling approach.

Furthermore, both the Likelihood Ratio (LR) test and Wald test reject the null hypothesis, indicating that the SDM provides a more accurate estimation compared with its nested models. The Hausman test results show that under both spatial weight matrices, the null hypothesis that the random effects model is preferred over the fixed effects model is rejected. Therefore, in both cases, this study reports the regression results of the SDM with fixed time effects.

Table 10. Diagnostic Tests for Establishing the Spatial Durbin Model

Tests	Null Hypothesis	Geographic Distance Matrix		Geographic Adjacency Matrix	
		Statistic	p-value	Statistic	p-value
LM Tests	LM test for no spatial autocorrelation in the error term	7.193	0.010	0.853	0.360
	Robust LM test for no spatial autocorrelation in the error term	4.229	0.040	38.782	0.000
	LM test for no spatial lag of the dependent variable	106.631	0.000	40.666	0.000
	Robust LM test for no spatial lag of the dependent variable	103.667	0.000	78.594	0.000
Wald Tests	Whether the SDM can be simplified to the SAR model	86	0.000	117.47	0.000
	Whether the SDM can be simplified to the SEM model	110.12	0.000	192.03	0.000
Hausman Tests	Random effects are preferred over fixed effects	112.86	0.000	142.9	0.000

3) Results of the Spatial Durbin Model Analysis

Based on the preceding diagnostic tests, this study adopts the Spatial Durbin Model (SDM) and incorporates the green finance variable (lngf) along with its squared term ($lngf^2$) to explore potential nonlinear effects. To ensure robustness and assess the sensitivity of spatial dependence structures, two types of spatial weight matrices—geographical contiguity and geographical distance—are employed. This allows for a comprehensive investigation of the direct effects of green finance on local digital economy development as well as the indirect spillover effects on neighboring provinces.

(1) The inverted U-shaped nonlinear effect of green finance within provinces

The empirical results indicate that green finance exerts a significant inverted U-shaped nonlinear effect on digital economy development at the provincial level. Specifically, the coefficients of the linear green finance term (lngf) are positive and statistically significant under both weight matrices (0.2425 for contiguity and 0.2431 for distance, $p < .01$), while the squared term ($lngf^2$) is negative and significant (−0.0217 and −0.0210, $p < .05$). These findings suggest that, at the early stages, green finance promotes digital economy growth by optimizing resource allocation, guiding green technology investment, and fostering green innovation. However, as the level of green finance continues to rise, its marginal contribution diminishes and eventually turns negative, forming a typical inverted U-shaped trajectory.

This nonlinear mechanism implies that the policy effects of green finance are stage-dependent. In regions with weaker institutional foundations or higher financial resource concentration, the excessive expansion of green finance may trigger resource misallocation, regulatory arbitrage, or financial risk spillovers, which ultimately hinder the sustainable growth of the digital economy. Thus, striking a balance in the pace and structural orientation of green finance—while avoiding “over-greenification”—is essential to enhancing policy efficiency.

(2) The nonlinear spatial spillover effects of green finance

Of greater policy relevance are the spatial spillover effects, namely, the impact of neighboring provinces’ green finance development on local digital economy performance. The regression results of the spatial lag terms (Wx) show that the coefficients of the first-order green finance term (Wx.lngf) are negative and significant at the 1% level under both matrices (−0.2410 for contiguity and −1.4089 for distance). This indicates that green finance expansion in neighboring provinces exerts a strong negative spillover effect on the local digital economy. Such an outcome may reflect interprovincial "siphon effects" or "competitive crowding-out effects," whereby the rapid concentration of green finance resources in surrounding regions attracts high-quality factors, project funding, and talent away from the local province, thereby weakening its digital economy development potential.

Moreover, the squared term of the spatial lag (Wx.lngf²) is also significantly negative (−0.1139 and −0.4307, $p < .01$), suggesting that this negative spillover effect is not linearly incremental but intensifies nonlinearly as the level of green finance in neighboring provinces rises. Once adjacent regions reach a high-density or strongly agglomerated state of green finance, the "attraction–crowding-out" mechanism becomes more pronounced, further widening interprovincial disparities in digital economy development.

(3) Spatial dependence structure

The spatial autoregressive coefficient (ρ) is significantly negative under both weight matrices (−0.3142 and −0.9029, $p < .01$), confirming the presence of a negative spatial dependence structure in China's regional digital economy development. This competitive structure indicates that improvements in one province's digital economy are often accompanied by relative disadvantages in neighboring regions, resembling a "zero-sum game" dynamic. This finding is consistent with the negative spatial spillover effects of green finance, highlighting the pronounced imbalance in regional resource allocation, policy coordination, and digital infrastructure development.

(4) Robustness test: consistency across spatial weight specifications

A comparison of results under the two spatial weight matrices reveals strong consistency in the direction and significance of the green finance variables. The estimated coefficients of the core variables vary only marginally, underscoring the robustness of the identified inverted U-shaped nonlinear effect and the negative spatial spillover effect of green finance. Regardless of whether spatial relationships are defined by geographical contiguity or physical distance, the nonlinear structure and spillover mechanisms remain robust and consistent, thereby reinforcing the reliability of the study's conclusions.

Table 11. Results of the Spatial Durbin Model Analysis

		Geographic Adjacency Matrix	Geographic Distance Matrix
		lnde	lnde
Main	lngf	0.2425***	0.2431***
		-5.0916	-5.4111
	lngf2	-0.0217**	-0.0210**
		(-2.1232)	(-2.1715)
	lnhjgz	-0.0538***	-0.0443***
		(-3.1427)	(-2.5959)
	lnczzc	-0.1176***	-0.1748***
		(-2.6274)	(-3.9066)
	lnczhl	0.5436***	0.5485***
		-10.8702	-11.5444
	lnxfsp	-0.0422	-0.0567
		(-0.5263)	(-0.7727)
Wx	lngf	-0.2410***	-1.4089***

		(-2.6867)	(-4.8998)
	lngf2	-0.1139***	-0.4307***
		(-6.1596)	(-7.2030)
	lnhjgz	0.1142***	0.4203***
		-3.3559	-4.0222
	lnczzc	-0.3153***	-1.4898***
		(-3.4917)	(-5.0774)
	lnczhl	0.4186***	1.3587***
		-4.0127	-4.7356
	lnxfsp	-0.5813***	-1.0409***
		(-4.3830)	(-2.8026)
Spatial	rho	-0.3142***	-0.9029***
		(-6.3642)	(-5.4467)
Variance	sigma2_e	0.0761***	0.0735***
		-18.8168	-19.1653

In summary, the empirical results based on the Spatial Durbin Model (SDM) demonstrate that green finance exerts a pronounced inverted U-shaped local effect and a nonlinear spatial spillover effect on digital economy performance. On the one hand, green finance significantly stimulates the development of the local digital economy in its early stages; however, its marginal contribution diminishes over time and eventually turns negative as the scale of green finance expands. On the other hand, the expansion of green finance in neighboring regions generates a salient “siphon effect” and “competitive crowding-out effect” on the local digital economy. Such inhibitory mechanisms are particularly pronounced when adjacent regions exhibit higher levels of green finance.

These findings highlight the nonlinear, asymmetric, and spatially heterogeneous characteristics of the influence of green finance on regional digital economies. They further underscore the necessity for policymakers to carefully consider the potential spatial tensions and developmental limits associated with the expansion of green finance. Therefore, it is imperative to establish inter-regional coordination and complementary policy mechanisms for green finance development in order to mitigate possible competitive crowding-out effects and to foster the synergistic and sustainable development of both green finance and the digital economy across regions.

5. Conclusion

Drawing on provincial panel data from 2000–2023, this study employs threshold and spatial econometric models to investigate the nonlinear and spatial spillover effects of green finance on China’s digital economy. The results demonstrate that green finance has a significant inverted U-shaped impact on digital economy development. At the early stage, it effectively channels financial resources toward green technologies and digital industries, accelerating innovation and informatization. However, when green finance expands excessively, its marginal benefits decline due to information asymmetry, market congestion, and inefficient capital allocation.

From a spatial perspective, the study identifies clear competitive spillover effects: the rapid expansion of green finance in neighboring regions can siphon investment and digital talent, thereby weakening local digital economy growth. This highlights the need for cross-regional coordination mechanisms and integrated financial–informatic governance systems.

Conceptually, the findings emphasize that green finance should be viewed not only as a financial instrument but also as an **information-driven service platform** that enhances data circulation, supports digital infrastructure, and strengthens smart regulation. Policymakers should focus on (1) improving the quality and structure of digital green finance products through big data and AI-enabled risk management; (2) developing collaborative digital platforms for interregional green financial governance; and (3) promoting balanced and sustainable development of the digital economy within a unified national informatics framework.

This research provides new evidence for the construction of **data-driven fiscal and financial service systems**, offering theoretical and practical insights for the Journal of Logistics, Informatics and Service Science community in advancing smart governance, regional coordination, and sustainable digital transformation.

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