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Interactive Effects Between Green Finance and the Digital Economy Across Chinese Provinces: Evidence from a Simultaneous Equation Model

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Abstract. This study employs provincial panel data from China spanning 2010 to 2023 to construct a simultaneous equation system, using the Three-Stage Least Squares (3SLS) method to systematically examine the bidirectional interactive relationship between green finance and the digital economy, as well as their regional heterogeneity. The indices of green finance and the digital economy are first measured using the entropy weighting method. Based on these indices, both static and dynamic simultaneous equation panel models are developed to investigate the two-way interaction mechanisms between the two systems, followed by robustness and regional heterogeneity analyses.

The empirical results reveal a significant and positive bidirectional causal relationship and endogenous feedback mechanism between green finance and the digital economy in China. Specifically, green finance substantially promotes the development of the digital economy, while the reverse impact of the digital economy on green finance is even stronger. Both variables exhibit significant temporal lag effects and path dependence: the stimulating effect of green finance demonstrates long-term persistence, whereas the driving effect of the digital economy is more immediate. These findings confirm the robustness and sustainability of their interactive relationship. Furthermore, pronounced regional heterogeneity is observed between China's northern and southern provinces. The northern region exhibits a "green finance–driven" model, in which green financial instruments play a dominant role in promoting digital economic growth. In contrast, the southern region follows a "digital economy–driven" pattern, where digital innovation significantly enhances the expansion and efficiency of green finance.

From a policy perspective, the findings suggest that China should promote institutionalized synergy between green finance and the digital economy through multidimensional approaches, including collaborative governance, long-term incentive mechanisms, regional coordination, and digital regulatory frameworks. Such integrated strategies will be essential for fostering the co-evolution and mutual reinforcement of green and digital transformations in the pursuit of sustainable development.

Keywords: Green Finance; Digital Economy; Simultaneous Equation Model; Regional Heterogeneity

1. Introduction

Against the backdrop of intensifying global climate change and mounting ecological pressures, green finance and the digital economy have gradually emerged as two pivotal engines driving China's high-quality and sustainable economic transformation. Green finance, through instruments such as credit, investment, and insurance, channels financial resources toward energy conservation, clean energy, and low-carbon industries, thereby providing critical capital support for the coordination of economic growth and ecological protection (Chen & Shen, 2022). Meanwhile, the digital economy, empowered by new-generation technologies such as big data, artificial intelligence, cloud computing, and blockchain, enhances the efficiency of economic systems and fosters industrial upgrading, playing a crucial role in improving economic quality and accelerating green transformation (Jin, 2025). The functional synergy between green finance and the digital economy thus provides a novel pathway toward achieving China's "dual-carbon" targets and sustainable development strategy.

China's recent policy frameworks further underscore the strategic alignment between these two domains. For instance, *the 14th Five-Year Plan for the Development of the Digital Economy explicitly* calls for "digitalization to drive greening and greening to enhance digitalization," thereby realizing a dual-engine model for high-quality growth. This policy orientation not only demonstrates the intrinsic interconnection between green finance and the digital economy but also establishes a robust institutional and policy foundation for academic inquiry (Zhou, 2024). Against this policy backdrop, examining the interactive relationship between green finance and the digital economy holds significant theoretical and practical implications for understanding their joint roles in fostering green and digital transitions.

Although the existing literature has explored the nexus between green finance and the digital economy to some extent, several limitations persist. First, most studies emphasize a unidirectional causal relationship. Some scholars argue that green finance promotes the development of the digital economy by channeling financial resources toward the green upgrading of digital industries (Xie & Zhou, 2023; Cao & Zhang, 2025). Others contend that the digital economy can in turn stimulate green finance by alleviating information asymmetries, improving financing efficiency, and enhancing financial inclusiveness (Wang et al., 2024). However, the relationship between green finance and the digital economy is inherently interactive and mutually reinforcing, rather than one-directional. Research limited to a single causal direction fails to capture the complex and dynamic nature of this interdependence.

Second, most existing studies rely on traditional regression frameworks, often overlooking the potential endogeneity and simultaneity inherent in this relationship. Green finance may indeed foster digital economic development, but the expansion of the digital economy can also promote the deepening of green finance. This suggests a bidirectional and simultaneous causality between the two systems. To address this issue and mitigate potential estimation bias, this study employs a simultaneous equations model (SEM) to empirically examine their mutual influence.

To fill the aforementioned research gaps, this paper aims to systematically investigate the interactive relationship and spatial effects between green finance and the digital economy across Chinese provinces. Specifically, it pursues three objectives: (1) to test the promoting effect of green finance on digital economic development; (2) to examine the feedback effect of the digital economy on green finance; and (3) to construct a simultaneous equations model that captures their bidirectional interaction and mitigates endogeneity bias, thereby revealing the simultaneity inherent in their relationship.

The main contributions of this study are threefold. First, in terms of research perspective, it transcends the traditional unidirectional framework by emphasizing the two-way interaction mechanism between green finance and the digital economy, providing a more comprehensive understanding of their dynamic relationship. Second, methodologically, it introduces the simultaneous equations model to characterize this interaction systematically, offering a novel analytical framework that effectively addresses endogeneity and can serve as a methodological reference for future studies. Third, from a policy perspective, this study provides empirical evidence and actionable insights for promoting the synergistic development of green finance and the digital economy in the context of China's green transformation.

In summary, the interaction between green finance and the digital economy represents not only a frontier issue in theoretical research but also a pressing practical challenge. By adopting a bidirectional analytical perspective, this study seeks to elucidate the internal mechanisms linking these two growth drivers and contribute new academic insights and policy recommendations toward achieving China's low-carbon transition and high-quality development.

2. Literature Review

In the current context of global economic transformation and China's "dual-carbon" strategy, green finance and the digital economy have emerged as two critical drivers for promoting high-quality economic development. Green finance facilitates low-carbon and sustainable development through optimized resource allocation and policy guidance, while the digital economy leverages information technologies, the internet, and data resources as core elements to drive industrial upgrading and structural adjustment. These two domains are not isolated; rather, they interact closely, attracting increasing attention in both theoretical and empirical research.

2.1. The Impact of Green Finance on the Digital Economy

Green finance exerts a profound influence on the digital economy through mechanisms such as capital supply, institutional constraints, and cross-regional spillovers. Existing studies generally consider green finance not only as a key instrument for green economic transformation but also as an indirect driver of digital economic development. Specifically, its influence can be articulated in three dimensions: capital support, institutional pressure, and regional spillovers.

First, green finance injects momentum into the digital economy through capital support mechanisms. Instruments such as green credit, green bonds, and green funds, guided by policy, provide essential financial resources for green technology adoption and the digital upgrading of industries (Cao & Zhang, 2025). For example, the application of technologies in clean energy, smart transportation, and green building sectors requires substantial financial investment, which largely relies on channels facilitated by green finance. Through this capital support, digital economy-related technologies and industries can expand rapidly, promoting the construction and dissemination of digital infrastructure.

Second, green finance promotes the digitalization of enterprises via institutional pressure mechanisms. Green finance requires financial institutions to consider environmental risks and carbon emission constraints in credit allocation and obliges enterprises to enhance compliance in information disclosure and risk management. To secure green financing, firms are incentivized to leverage digital tools to improve environmental governance, such as employing big data for carbon monitoring or blockchain for supply chain transparency. This external pressure accelerates corporate digital transformation, thereby advancing the development of the digital economy (Cui & Ma, 2023).

2.2. The Impact of the Digital Economy on Green Finance

Conversely, the digital economy empowers green finance through technological innovation and efficiency enhancement, providing platforms, tools, and improving both transparency and inclusiveness, thereby enhancing the overall quality and sustainability of green finance.

First, the digital economy offers technological support for green finance. Big data analytics can enhance the efficiency of risk identification and credit evaluation in green finance. For instance, financial institutions can analyze enterprises' carbon emissions, energy consumption, and environmental performance data to more accurately assess the feasibility of green projects, reducing financing risks. Artificial intelligence (AI) can further optimize green credit approval, green securities pricing, and carbon market transactions, thereby improving the operational efficiency of the green financial system (Cao & Zhang, 2025).

Second, the digital economy enhances the operational environment of green finance via information transparency mechanisms. Blockchain technology enables full-process traceability and verification of green financial products, ensuring that funds are genuinely allocated to green projects and mitigating “greenwashing” risks. This transparency strengthens market trust in green finance and enhances the effectiveness of policy implementation (He & Hu, 2022).

Third, the digital economy significantly expands the coverage of green finance through inclusiveness mechanisms. Traditional green finance often focuses on large enterprises and priority projects. Digital economy platforms, including internet finance and mobile payment technologies, allow small and medium-sized enterprises (SMEs) and rural areas to participate in green finance initiatives, promoting a broader green transformation. For example, digital platform-based green inclusive loans provide financing for rural clean energy projects, facilitating balanced urban-rural green development (Wang et al., 2024).

2.3. The Relationship between Green Finance and the Digital Economy

Taken together, existing research from both theoretical and empirical perspectives has sufficiently demonstrated the significant impact of green finance on the digital economy as well as the significant influence of the digital economy on green finance. This raises a further question: What is the bidirectional interaction mechanism and structural pattern between green finance and the digital economy? In essence, green finance and the digital economy do not constitute a simple one-way causal chain; rather, they form an interactive and co-evolving ecosystem.

From a theoretical perspective, the relationship between green finance and the digital economy is not unidirectional but characterized by mutual influence and symbiotic interaction. In November 2021, China’s Central Cyberspace Affairs Commission issued the 14th Five-Year Plan for National Informatization (hereafter “the Plan”), which outlines the strategic deployment for China’s digital and information development over the next five years. The Plan emphasizes accelerating the coordinated advancement of economic digitalization and greening, deepening ecological civilization construction, promoting a digital-driven green transition and a green-oriented digital transition, and fostering the integrated and reciprocal development of both spheres (Zhou, 2024). The integration and coordinated evolution of green finance and the digital economy emerge in two major directions. On one hand, digital technologies—represented by big data, blockchain, and the Internet of Things—facilitate the advancement of the green financial system by providing upstream–downstream linkage platforms and by establishing information-matching mechanisms that reduce mismatches and enhance capital allocation efficiency (Ren et al., 2025; Xu et al., 2025). On the other hand, green financial instruments—such as green credit, green investment, and green insurance—deeply integrate with digital industries, enabling green finance to effectively promote the low-carbon transformation of the digital sector and to support the sustainable development of the digital economy (Yu et al., 2024).

Moreover, Zhang and Rong (2025) argue that the digital economy enhances transparency within the green financial system through tools such as monitoring networks and blockchain-based verification—illustrated, for instance, in the transparent prediction of returns for agriculture-forestry investment projects. In turn, green finance drives the rapid application of digital technologies within green industries, thereby forming a feedback loop driven jointly by capital and technology, ultimately reinforcing the foundational integration of the green–digital ecosystem. Zhang et al. (2025) further contend that embedding digital technologies into the green financial system enhances life-cycle management efficiency. Blockchain-based securitization of fixed assets, for example, reduces the financial management complexity associated with carbon-emission projects. Such technological embedding not only increases financial efficiency but also strengthens the reliability and transparency of environmental projects. Xu et al. (2025) similarly suggest that green finance promotes the low-carbon upgrading of digital technologies through financial support—such as the issuance of green bonds for smart energy system construction and intelligent transportation management platforms—thereby indirectly fostering upgrading within the digital technology industry chain through reductions in long-term energy costs.

From an empirical perspective, Zhou (2024) finds a reciprocal relationship between green finance and the digital economy. Based on panel data for 41 prefecture-level cities in the Yangtze River Delta region from 2011 to 2020, Zhou measures the development levels and coupling degrees of green finance and the digital economy and characterizes the coupled dynamics and spatiotemporal evolution patterns between the two systems. Beyond this study, publicly available literature indicates that only a limited number of empirical papers—particularly those using econometric models—have examined the interactive linkage between China's green finance and the digital economy.

Regarding simultaneous equation models, many scholars have applied them to various empirical studies in economics. For instance, Yan et al. (2024) argue that because the digital economy and the real economy are endogenously related, single-equation models may overlook endogeneity problems among variables; therefore, they construct a system of simultaneous equations to examine their interactive effects. Hu et al. (2020), when analyzing the transmission mechanisms, spatial spillover effects, and regional heterogeneity among foreign trade, technological progress, and economic growth, account for simultaneity among core variables and thus establish a panel simultaneous equation model. Similarly, Wang (2016) employs a simultaneous equation system to investigate the relationship between China's economic growth and environmental pollution. Liu and Xu (2024) apply a simultaneous equation framework to examine the income–consumption linkage of households under the influence of digital finance. Guan et al. (2025) likewise adopt a simultaneous equation framework to explore the interactive effects between digital finance and the equalization of public services.

In research on the bidirectional interaction between provincial-level green finance and the digital economy in China, the application of such methodological frameworks appears limited according to publicly available sources. Nevertheless, given the theoretically reciprocal relationship and potential mutual impact between provincial green finance and the digital economy—and to address endogeneity issues inherent in their interaction—this study employs a system of simultaneous equations to investigate, the bidirectional and co-evolutionary linkage between provincial-level green finance and the digital economy in China.

3. Research Methodology

3.1. Variable Definition and Measurement

1)Digital Dconomy

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(Li, Huang, & Yao, 2025).

Table1. 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)Green Finance

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)(Li, Huang, & Yao, 2025).

Table2. 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

Given the significant impact of green finance on the digital economy, as well as other potential factors influencing its development, this study incorporates several control variables in the equation where the digital economy serves as the dependent variable. Specifically, environmental regulation (hjgz), fiscal support intensity (czzc), and urbanization level (czhl) are included as key controls. Detailed operational definitions of these variables are provided in Table 3.

Table 1. Operational Definitions of Control Variables for the Digital Economy

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

Considering the significant influence of the digital economy on green finance, as well as other potential factors affecting its development, this study incorporates several control variables in the equation where green finance serves as the dependent variable. Specifically, openness to foreign investment (dwkf), industrial structure (cygd), and economic development level (mgdpl) are included as key controls. etailed operational definitions of these variables are provided in Table 4.

Table 2. Operational Definitions of Control Variables for Green Finance

Control Variable	Operational Definition
Openness to Foreign Investment (dwkf)	Foreign direct investment / GDP
Industrial Structure (cygd)	Output of tertiary industry / Output of secondary industry
Economic Development Level (mgdpl)	GDP / Total population

3.2 Data Collection and Composite Index Construction

To ensure data completeness and accessibility, this study collects panel data from 30 provincial-level administrative regions in China (excluding Tibet, Taiwan, Macau, and Hong Kong) for the period 2000–2023. For the digital economy indicators, data are primarily sourced from the official website of the National Bureau of Statistics of China, the China Academy of Information and Communications Technology, relevant industrial and information technology research reports, provincial statistical yearbooks, the annual China Digital Economy Development Report, China Statistical Yearbook, China Information Yearbook, and China Information Industry Yearbook (Li, Huang, & Yao, 2025).

For the green finance indicators, data on green credit, green bonds, and green funds are obtained from the China Financial Statistics Yearbook; green investment data from the China Environmental Statistics Yearbook; green insurance data from the China Insurance Yearbook; and other green support data from the China Statistical Yearbook. Carbon emissions data are derived from the CEADs China Carbon Accounting Database. Data for all control variables are collected from the China Statistical Yearbook, the China Environmental Statistics Yearbook, and the China National Research Data Service Platform (Li, Huang, & Yao, 2025).

The composite green finance index (hereafter, Green Finance) is constructed using the entropy weight method following the approach of Shi (2023). Similarly, the composite digital economy index (hereafter, Digital Economy) is constructed using the entropy weight method following Wang et al. (2021). To enhance the stationarity of the time series data, all variables are transformed using natural logarithms.

3.3 Model Specification

To investigate the intrinsic relationship between digital economy and green finance, both variables are treated as endogenous in a system of simultaneous equations. A provincial-level panel simultaneous equations model is constructed to incorporate digital economy and green finance within the same equation system. The model is specified as follows:

$$\mathrm{lnde}_{i,t} = \alpha + \alpha_1 \mathrm{lngf}_{i,t} + \sum_{j=1}^{3} \alpha_j\, \mathrm{acontrol}_{j,t} + u_i + \varepsilon_{i,t} \quad (1)$$

$$\mathrm{lngf}_{i,t} = \beta + \beta_1 \mathrm{lnde}_{i,t} + \sum_{j=1}^{3} \beta_j\, \mathrm{bcontrol}_{j,t} + u_i + \varepsilon_{i,t} \quad (2)$$

Equation (1) is designed to examine the effect of green finance on the digital economy, while Equation (2) tests the impact of the digital economy on green finance. Together, these two equations constitute a complete feedback loop. In the model, lnde denotes the digital economy, and lngf represents the green finance. $\mathrm{acontrol}_j$（j=1,2,3） correspond to environmental regulation, fiscal support, and urbanization rate, whereas$\mathrm{bcontrol}_j$（j=1,2,3）correspond to the levels of openness, industrial structure, and economic development.

To further investigate the dynamic interactions between green finance and the digital economy, first-order lagged terms of the endogenous variables are incorporated into Equations (1) and (2), leading to the following dynamic panel simultaneous equations model:

$$\ln de_{i,t} = \alpha + \alpha_0 \ln de_{i,t-1} + \alpha_1 \ln gf_{i,t} + \sum_{j=1}^{3} \alpha_j \, acontrol_{j,t} + u_i + \varepsilon_{i,t} \quad (3)$$

$$\ln gf_{i,t} = \beta + \beta_0 \ln gf_{i,t-1} + \beta_1 \ln de_{i,t} + \sum_{j=1}^{3} \beta_j \, bcontrol_{j,t} + u_i + \varepsilon_{i,t} \quad (4)$$

In Equation (3), the first-order time-lagged term of the digital economy is included, whereas Equation (4) incorporates the first-order lag of green finance.

There are two broad categories of estimation methods for simultaneous equation models. The first category is single-equation estimation methods, which include ordinary least squares (OLS), indirect least squares (ILS), two-stage least squares (2SLS), and generalized method of moments (GMM). However, these methods treat each equation independently and may ignore correlations among the disturbance terms across equations, which can lead to inefficient estimates. The second category is system estimation methods, among which the Three-Stage Least Squares (3SLS) approach is widely used.

Considering that the primary focus of this study is to investigate the intrinsic relationship between green finance and the digital economy, the 3SLS system estimation method is adopted. This approach efficiently accounts for the interdependencies among equations and the potential contemporaneous correlation of error terms, providing consistent and efficient estimates of the dynamic interactions between the variables.

4. Results and Discussion

4.1. Descriptive Statistics

As shown in Table 5, there exist notable differences between the maximum and minimum values of green finance and the digital economy across Chinese provinces. This variation reflects the considerable inter-provincial disparities in the development of green finance and digital economy in China. Similarly, the development levels of environmental regulation, government support, urbanization rate, and consumption also exhibit significant provincial heterogeneity, indicating that substantial gaps exist among provinces in terms of digital economy development.

Table 3. Descriptive Statistics

VarName	Mean	SD	Min	Median	Max
lnde	-1.5759	0.738	-4.46	-1.51	-0.06
lngf	-1.3893	1.026	-5.89	-1.00	-0.05
lnhjgz	-5.8751	0.954	-9.68	-5.75	-3.47
lnczzc	-1.6137	0.432	-2.67	-1.61	-0.28
lnczhl	-0.6902	0.343	-1.91	-0.64	-0.11
lndwkf	-4.2695	1.232	-10.64	-4.03	-1.81
lncygd	0.8511	0.057	0.73	0.85	1.05
lnmgdp	10.2763	0.890	7.92	10.43	12.21

4.2. Pre-Modeling Assumption Tests

When conducting empirical modeling with panel data containing time series, it is generally required that the variables exhibit significant correlations and stationarity. Prior to formal modeling, the following preconditions were verified to ensure robustness. To improve the stationarity of the data series, all variables were first logarithmically transformed.

1)Correlation Analysis

Correlation analysis was conducted to preliminarily assess the relationships among the variables and inform subsequent empirical modeling. The results indicate that, for the 30 provincial-level administrative regions in China (excluding Tibet, Hong Kong, Macau, and Taiwan) over the period 2000–2023, green finance and digital economy exhibit a significant positive correlation. Moreover, green finance is significantly correlated with all control variables, and the digital economy is also significantly positively correlated with its respective control variables.

Table 4. Correlation Analysis Results

	lnde	lngf	lnhjgz	lnczzc	lnczhl	lndwkf	lncygd	lnmgdp
lnde	1							
lngf	.783**	1						
lnhjgz	-.574**	-.487**	1					
lnczzc	-.111**	-.434**	0.05	1				
lnczhl	.713**	.459**	-.430**	.177**	1			
lndwkf	.291**	.450**	-0.04	-.559**	.197**	1		
lncygd	.639**	.321**	-.387**	.119**	.724**	.101**	1	
lnmgdp	.811**	.494**	-.567**	.199**	.848**	0.033	.743**	1

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

2)Stationarity Test

To ensure the suitability of the panel data for modeling, the stationarity of all variables was examined using the Fisher and Levin-Lin-Chu (LLC) unit root tests on their first-order differences. As shown in Table 7, all variables are stationary at the first difference and exhibit significant results, indicating that the data series meet the stationarity requirement. Therefore, the dataset is appropriate for panel data-based empirical modeling.

Table5. Stationarity Test of Variables

variable	Test statistical indicators			Statistic	p-value
D.lnde	Fisher	Inverse chi-squared(60)	P	670. 338	0.000
		Inverse normal	Z	−21. 547	0.000
		Inverse logit t(154)	L*	−33. 825	0.000
		Modified inv. chi-squared	Pm	670. 338	0.000
	Levin–Lin–Chu		Adjusted t*	-15.235	0.000
D.lngf	Fisher	Inverse chi-squared(60)	P	673. 689	0.000
		Inverse normal	Z	−22. 183	0.000
		Inverse logit t(154)	L*	−34. 014	0.000
		Modified inv. chi-squared	Pm	56. 022	0.000
	Levin–Lin–Chu		Adjusted t*	-15.489	0.000
D.lnhjgz	Fisher	Inverse chi-squared(60)	P	360. 362	0.000
		Inverse normal	Z	−14. 341	0.000
		Inverse logit t(154)	L*	−18. 060	0.000
		Modified inv. chi-squared	Pm	27. 419	0.000
	Levin–Lin–Chu		Adjusted t*	-7.316	0.000
D.lnczzc	Fisher	Inverse chi-squared(60)	P	251. 650	0.000
		Inverse normal	Z	−10. 334	0.000
		Inverse logit t(154)	L*	−12. 304	0.000
		Modified inv. chi-squared	Pm	17. 495	0.000
	Levin–Lin–Chu		Adjusted t*	-8.911	0.000
D.lnczhl	Fisher	Inverse chi-squared(60)	P	290. 944	0.000
		Inverse normal	Z	−12. 333	0.000
		Inverse logit t(154)	L*	−14. 585	0.000
		Modified inv. chi-squared	Pm	21. 082	0.000
	Levin–Lin–Chu		Adjusted t*	-6.846	0.000
D.lndwkf	Fisher	Inverse chi-squared(60)	P	245.8863	0.000
		Inverse normal	Z	-9.285	0.000
		Inverse logit t(154)	L*	-11.3392	0.000

		Modified inv. chi-squared	Pm	16.969	0.000
	Levin–Lin–Chu		Adjusted t*	-7.5173	0.000
D.lncygd	Fisher	Inverse chi-squared(60)	P	251.122	0.000
		Inverse normal	Z	−9.833	0.000
		Inverse logit t(154)	L*	−11.995	0.000
		Modified inv. chi-squared	Pm	17.447	0.000
	Levin–Lin–Chu		Adjusted t*	-8.992	0.000
D.lnmgdp	Fisher	Inverse chi-squared(60)	P	108.048	0.000
		Inverse normal	Z	−4.334	0.000
		Inverse logit t(154)	L*	−4.280	0.000
		Modified inv. chi-squared	Pm	4.386	0.000
	Levin–Lin–Chu		Adjusted t*	-6.299	0.000

In summary, the correlation analysis and unit root tests indicate that there exists a significant relationship between digital economy and green finance, as well as between each of these two variables and the corresponding control variables. Moreover, all variables are stationary at the first difference, satisfying the preconditions for panel data regression modeling. Therefore, the dataset is suitable for constructing and estimating econometric models.

4.3. Empirical Analysis

1）Static Panel Model Analysis

Based on the discussion in Section 3.3, this study employs provincial panel data from China covering 2010–2023 and applies the Three-Stage Least Squares (3SLS) method to estimate a static panel system of simultaneous equations. The estimation results are presented in Table 8.

In the equation with digital economy (lnde) as the dependent variable, the coefficient of green finance (lngf) is 0.8944 ($z = 13.07$, $p < 0.001$), indicating a strong positive effect of green finance on the development of the digital economy. Specifically, a 1% increase in green finance is associated with an average increase of approximately 0.89% in the digital economy. This finding highlights green finance as a crucial financial force driving the expansion and innovation upgrading of China's digital economy.

Additionally, environmental regulation (lnhjgz) has a coefficient of 0.0705 ($p = 0.012$), showing a significant positive impact, suggesting that moderate environmental regulation policies facilitate the development of the digital economy. Fiscal support (lnczzc) exhibits a coefficient of 0.6454 ($p < 0.001$), indicating a substantial stimulative effect of government expenditure. Increased fiscal investment not only directly enhances digital infrastructure, R&D investment, and the innovation environment but also guides social capital to participate actively in digital industries. Urbanization (lnczhl) has a coefficient of 0.2198 ($p = 0.024$), reflecting a positive effect on digital economy development; urbanization contributes to the improvement of information infrastructure, the expansion of consumption markets, and the agglomeration of skilled labor and innovative resources, thereby promoting digital economic growth. Overall, the digital economy equation reveals a multi-dimensional policy transmission mechanism: green finance provides financial and conceptual support, environmental regulation incentivizes innovation, fiscal support strengthens resource allocation, and urbanization promotes the agglomeration of innovation factors, jointly fostering the growth of the digital economy.

In the equation with green finance (lngf) as the dependent variable, the coefficient of digital economy (lnde) is 3.0389 ($z = 13.19$, $p < 0.001$), demonstrating a strong positive influence of digital economy on green finance. A 1% increase in digital economy corresponds to an average increase of approximately 3.04% in green finance, which is substantially larger than the reverse effect of green finance on digital economy. This underscores the critical role of digital technologies in promoting green financial development.

Foreign openness (lndwkf) has a coefficient of -0.1618 ($p < 0.001$), indicating that increased openness exerts a short-term negative impact on green finance. This may reflect that foreign-invested enterprises initially focus on traditional manufacturing or high-energy industries, or that the current foreign investment market lacks a comprehensive green certification system, causing a deviation between capital flows and green finance objectives. From a dynamic perspective, this result highlights the need for policies that guide multinational capital toward green transformation and sustainable finance. Industrial structure (lncygd) has a coefficient of -1.7056 ($p = 0.023$), also showing a negative effect. Despite the rising share of the tertiary sector being a marker of structural upgrading, certain service sub-sectors (e.g., traditional finance, logistics, and real estate) have not fully integrated into the green transformation, indicating a lagged effect between structural adjustment and green finance development. Economic development level (lnmgdp) has a coefficient of -1.3112 ($p < 0.001$), suggesting that GDP growth does not automatically translate into green finance expansion in the short term.

Overall, the 3SLS estimation clearly demonstrates a significant bidirectional linkage and endogenous feedback between provincial green finance (lngf) and digital economy (lnde) in China. In the system of equations, the estimated coefficient of green finance on digital economy is 0.894 ($p < 0.001$), while that of digital economy on green finance is 3.039 ($p < 0.001$), indicating a stable and positive interaction with high statistical significance, confirming the co-evolutionary mechanism between the two. The R-squared values further support these findings, with 0.5883 for the digital economy equation and 0.3064 for the green finance equation, suggesting that the model effectively explains the dynamic relationship structure between the variables. All coefficients are statistically significant at the 1% or 5% level. The chi-square statistics for the two equations are 1235.86 and 648.27, respectively, with corresponding p-values of 0.0000, confirming the overall statistical significance of the system and the reliability of the parameter estimates. These results provide a solid empirical basis for exploring the endogenous interaction mechanisms between green finance and digital economy.

Table 6. Estimation Results of the Static Panel Simultaneous Equations Model

	Lnde（1）	Lngf（2）
lnde		3.0389^{***}
		(13.1949)
lngf	0.8944^{***}	
	(13.0667)	
lnhjgz	0.0705^{**}	
	(2.5104)	
lnczzc	0.6454^{***}	
	(7.1962)	
lnczhl	0.2198^{**}	
	(2.2613)	
lndwkf		-0.1618^{***}
		(-3.8801)
lncygd		-1.7056^{**}
		(-2.2735)
lnmgdp		-1.3112^{***}
		(-8.2709)
_cons	1.2742^{***}	17.6350^{***}
	(3.9201)	(9.3331)
N	720	720
adj. R^2	0.5860	0.3037

2)Dynamic Panel Simultaneous Equations Model Analysis

To further examine the dynamic interaction between the digital economy and green finance over time, this study introduces the first-order time-lagged terms of the dependent variables into each equation of the static panel simultaneous equations model, constructing a dynamic panel system of simultaneous equations. The estimation results are presented in Table 9.

Overall, after including the lagged terms of lnde and lngf in the static panel system, the adjusted R-squared of the digital economy equation increased substantially from 0.5860 to 0.9649, while that of the green finance equation rose from 0.3037 to 0.9127. This indicates a pronounced dynamic inertia effect for both digital economy and green finance: past levels significantly and positively influence current levels.

In the static model, the contemporaneous effect of digital economy on green finance was 3.0389 ($p < 0.001$), demonstrating a strong and statistically significant positive effect. This suggests that, in the short term, higher digital economy levels correspond to a greater scale or activity of green finance, reflecting the facilitative role of digital technologies in financial innovation and green investment allocation. In the dynamic model, however, the contemporaneous effect of digital economy on green finance declines to 0.2361 ($p < 0.001$), while retaining statistical significance. The reduction in the coefficient mainly reflects the model's control for green finance's own inertia (L.lngf = 0.8152, $p < 0.001$), indicating that the net short-term contribution of digital economy is relatively smaller once historical levels of green finance are accounted for. This implies that the effect of digital economy on green finance operates not only through immediate impact but also indirectly via accumulated historical influence.

Similarly, in the static model, green finance has a contemporaneous effect of 0.8944 ($p < 0.001$) on digital economy, confirming that green financial inputs, green credit, and green investment significantly promote digital economy development. In the dynamic model, however, the contemporaneous effect decreases to 0.0219 ($p \approx 0.056$), while the coefficient for the lagged term of digital economy is extremely high (L.lnde = 0.8612, $p < 0.001$). This indicates that the development of digital economy is largely supported by its historical levels, and the short-term stimulating effect of green finance diminishes after controlling for inertia. Consequently, the positive role of green finance is more likely realized through long-term accumulation, policy continuity, and financial system development.

From the perspective of bidirectional interactions between green finance and digital economy, the static model reveals significant positive contemporaneous effects for both directions, suggesting mutual short-term reinforcement under policy or market conditions. In contrast, the dynamic model shows highly significant lagged coefficients for both digital economy and green finance (L.lnde: 0.8612; L.lngf: 0.8152), indicating strong path dependence and cumulative effects, with historical levels dominating current states. It is noteworthy that after accounting for dynamic inertia, the short-term effect of green finance on digital economy decreases substantially, whereas digital economy's short-term impact on green finance remains significant but weaker than in the static model. This indicates that the linkage between the two variables varies across time scales: digital economy may exert a more immediate influence on green finance, while green finance's facilitative effect requires long-term accumulation and institutional support to materialize.

Table7. Estimation Results of the Dynamic Panel Simultaneous Equations Model

	lnde(1)	Lngf(2)
lnde		0.2361***
		(4.7733)
L.lnde	0.8612***	
	(55.0685)	
lngf	0.0219*	
	(1.9095)	
L.lngf		0.8152***
		(37.0944)
lnhjgz	-0.0142**	
	(-2.2571)	
lnczzc	-0.0251	
	(-1.5878)	
lnczhl	0.0799***	
	(3.4844)	
lndwkf		0.0308***
		(2.8666)
lncygd		-0.5421*
		(-1.7163)
lnmgdp		-0.0380
		(-1.3177)
_cons	-0.1917***	1.1338***
	(-3.6086)	(3.1008)
N	690	690
adj. R^2	0.9649	0.9127

4)Robustness Analysis

Based on the estimation results of the static model in Table 8, the contemporaneous effect of digital economy on green finance is 3.0389 ($p < 0.001$), while that of green finance on digital economy is 0.8944 ($p < 0.001$), both exhibiting high statistical significance. This indicates a pronounced bidirectional interaction between the two variables under the condition that historical inertia and dynamic accumulation effects are not considered. After controlling for the first-order lagged terms of digital economy and green finance, the dynamic model similarly demonstrates positive bidirectional effects, with the contemporaneous effect of digital economy on green finance being 0.0219 ($p \approx 0.056$) and that of green finance on digital economy being 0.2361 ($p < 0.001$).

In terms of directional consistency, both the static and dynamic models support the core conclusion that digital economy and green finance exhibit mutually reinforcing positive interactions. Although the magnitudes of the contemporaneous effects in the dynamic model are lower than in the static model, the long-term trends and the positive relationship remain significant. This consistency suggests that improvements in digital economy can promote the development of green finance in the long run, while the expansion of green finance positively contributes to digital economy growth, thereby confirming the robustness of the bidirectional interaction mechanism.

Moreover, the high goodness-of-fit in the dynamic model (adjusted $R^2 = 0.9649$ for the digital economy equation and 0.9127 for the green finance equation) further reinforces the reliability of the static model conclusions. While the effects of control variables in the dynamic model exhibit some adjustments in magnitude and direction compared to the static model, the core positive interactive relationship remains unchanged. This consistency across different model specifications not only validates the robustness of the original results but also indicates that the bidirectional interaction between digital economy and green finance is both sustainable and dynamically stable over time, providing a solid empirical foundation for policy formulation and theoretical analysis.

5)Regional Heterogeneity Analysis

As noted by Tao and Huang (2022), regions in China exhibit substantial differences in resource endowments and economic development levels, resulting in spatial disparities in the development of the digital economy. Concurrently, green finance and digital economy also demonstrate significant regional development differences (Cui & Ma, 2023). To account for regional heterogeneity, this study follows the division approach of Tao and Huang (2022), Deng and Chen (2022), and Xu et al. (2021), classifying the sample into southern and northern regions for subgroup estimation of the simultaneous equations, in order to further explore the interaction between green finance and digital economy across regions. The regression results are presented in Table 10.

Overall, both southern and northern regions exhibit significant positive bidirectional linkages between digital economy and green finance. This robustness result confirms the generality and long-term stability of the endogenous interaction mechanism between the two variables, providing empirical support and policy implications for promoting coordinated regional development in China's integrated green and digital economy.

In the northern region, the promoting effect of green finance on digital economy is both significant and strong (coefficient = 0.995, t = 9.434, $p < 0.001$), while the reverse effect of digital economy on green finance is also significant (coefficient = 2.530, t = 15.772, $p < 0.001$), indicating a relatively stable bidirectional interaction mechanism. This result suggests that in northern provinces, green finance has become a key support for digital economy expansion. Financial instruments such as green credit, green investment, and green bonds facilitate industrial digitalization and low-carbon transformation. Simultaneously, the growth of the digital economy enhances the efficiency and transparency of green finance, forming a "technology empowerment—financial optimization—ecological improvement" cycle.

In the southern region, the effect of digital economy on green finance is relatively stronger (coefficient = 3.0803, t = 4.6955, $p < 0.001$), while the reverse effect of green finance on digital economy, although significant (coefficient = 2.5301, t = 15.7722, $p < 0.001$), is slightly weaker than in the north. This indicates a "digital-driven" interaction pattern in southern provinces, where digital economy development primarily provides growth opportunities, application scenarios, and risk identification mechanisms for green finance. With higher levels of digital infrastructure and innovation density, southern provinces leverage technologies such as big data, artificial intelligence, and blockchain to improve resource allocation efficiency, risk identification capacity, and capital flow transparency in green finance, thereby promoting its steady expansion.

In summary, the regional heterogeneity analysis reveals distinct interaction patterns between digital economy and green finance in China's north-south regions: the northern region exhibits a "green finance-driven" pattern, in which fiscal support and financial instrument innovation play a crucial role in promoting digital economy growth; whereas the southern region displays a "digital economy-driven" pattern, where digital infrastructure and technological innovation dominate resource allocation and risk control in green finance.

Table 8. Estimation results for Each Regional Subgroup

	Northern Region		Southern Region	
	lnde	lngf	lnde	lngf
lnde		2.5301***		3.0803***
		(15.7722)		(4.6955)
lngf	0.9945***		2.5301***	
	(9.4339)		(15.7722)	
lnhjgz	0.0500		0.0212	
	(1.2771)		(0.7922)	
lnczzc	0.8431***		-0.8762	
	(5.9409)		(-1.3684)	
lnczhl	-0.1840		-1.1300***	
	(-0.9357)		(-8.9289)	
lndwkf		0.0212		-0.4229***
		(0.7922)		(-2.7837)
lncygd		-0.8762		-4.5914*
		(-1.3684)		(-1.8030)
lnmgdp		-1.1300***		-1.0766***
		(-8.9289)		(-3.4591)
_cons	1.4439***	14.9648***	1.4439***	16.7607***
	(3.1522)	(10.5236)	(3.1522)	(3.0741)

5. Conclusions and Recommendations

5.1. Conclusions

Based on provincial panel data from China during 2010–2023, the empirical results from the Three-Stage Least Squares (3SLS) estimation and dynamic panel simultaneous equations models reveal a significant bidirectional positive linkage and endogenous feedback mechanism between green finance and the digital economy. This relationship remains highly robust and statistically significant across the national sample as well as in regional subgroup analyses, indicating that China's green finance system and digital economy are evolving in a coordinated and mutually reinforcing manner. Such a synergistic evolution provides empirical support for constructing a high-quality, low-carbon, and innovation-driven economic development framework.

First, at the national level, green finance exerts a significant promoting effect on the development of the digital economy. In the static panel model, a 1% increase in green finance corresponds, on average, to a 0.89% increase in digital economy levels, highlighting that the expansion of financial resources—including green credit, green bonds, and green investment—effectively supports digital infrastructure development, technological innovation investment, and sustainable industrial upgrading. Conversely, the reverse impact of the digital economy on green finance is even more pronounced, with a coefficient of 3.0389 ($p < 0.001$), demonstrating that digital transformation promotes market penetration and efficiency of the green finance system through fintech innovation, data governance, and improved information transparency. These findings indicate that China's green finance and digital economy are in a "technology-enabled, finance-optimized, sustainable growth" symbiotic phase, where their coordinated development generates new drivers for high-quality economic growth.

Second, from a dynamic perspective, both green finance and the digital economy exhibit significant temporal lag and path dependence. The dynamic panel model with first-order lagged terms shows lag coefficients above 0.8 ($p < 0.001$) for both variables, indicating pronounced inertia and historical accumulation effects. After controlling for such inertia, the immediate effect of the digital economy on green finance decreases from 3.0389 to 0.2361 but remains statistically significant, while the immediate effect of green finance on the digital economy decreases from 0.8944 to 0.0219, highlighting that the promoting effect of green finance is more long-term and strategic in nature. This dynamic pattern suggests that digital economy improvements can quickly stimulate green finance innovation and expansion in the short term, whereas the institutional and policy characteristics of green finance imply a more sustained and strategic influence over time. Overall, the positive interaction between the two variables is consistent in both direction and significance, confirming the robustness of the model results.

Third, the regional heterogeneity analysis reveals significant differences in the linkage patterns between green finance and the digital economy across northern and southern China. In the Northern Region, the interaction exhibits a “green finance-driven” pattern, with green finance strongly promoting the digital economy (coefficient = 0.9945, $p < 0.001$). This indicates that resource allocation, green credit expansion, and fiscal support play a key role in driving industrial digitalization and smart transformation. The reverse effect of the digital economy on green finance is also significant (coefficient = 2.5301, $p < 0.001$), forming a stable “dual-loop” feedback mechanism. In contrast, the Southern Region demonstrates a “digital economy-driven” pattern, where the digital economy exerts a stronger influence on green finance (coefficient = 3.0803, $p < 0.001$). This reflects the region’s characteristics of advanced digital infrastructure, high innovation density, and strong technological penetration, where the digital economy significantly enhances the allocation efficiency and risk identification capability of green finance through technological innovation, data flow, and intelligent regulatory mechanisms. The observed regional differences underscore the spatial non-equilibrium of the green finance–digital economy interaction in China, offering critical insights for promoting coordinated regional development.

In summary, the empirical evidence supports the existence of a robust, bidirectional, and regionally differentiated interaction between green finance and the digital economy in China, highlighting both the short-term and long-term mechanisms through which these systems co-evolve and reinforce one another.

5.2. Recommendations

China’s green finance and digital economy have established a long-term endogenous, co-evolving mechanism, exhibiting robustness across temporal scales and regional heterogeneity. By constructing a policy framework that is institutionalized, digitalized, and regionally coordinated, China can achieve mutual reinforcement between green finance and the digital economy, thereby promoting high-quality economic development and sustainable transformation. Based on the empirical findings, four key policy recommendations are proposed:

1)Strengthen the Coordinated Policy Framework for Green Finance and the Digital Economy: Governments should further integrate green finance standards with digital economy governance systems, fostering innovation in green financial products while embedding digital technologies deeply into financial supervision, risk assessment, and compliance processes. This approach would facilitate the emergence of a digitally empowered green financial ecosystem. In particular, areas such as carbon trading, green bonds, and sustainable investment should leverage digital technologies—including blockchain, artificial intelligence, and big data—to enhance market transparency, improve liquidity, and enable real-time monitoring, thereby promoting the development of a new green digital finance paradigm.

2)Establish Long-Term Incentive Mechanisms to Reinforce the Structural Accumulation Effect of Green Finance: Empirical results indicate that green finance exerts significant long-term and lagged effects on the digital economy. Therefore, policies should ensure continuity and stability in financial systems to sustain green capital investments. Governments can provide fiscal guidance, green credit incentives, and financial tax benefits to encourage banks, securities firms, and insurance companies to expand the supply of green financial products. This strategy would support the long-term integration of digital infrastructure and green innovation, ensuring that the growth of the digital economy is consistently aligned with sustainable development objectives.

3)Optimize Regional Differentiation Strategies and Promote North-South Coordination: Considering regional heterogeneity, policy measures should be tailored to local characteristics. In northern regions, where green finance plays a dominant role, emphasis should be placed on strengthening digital infrastructure and enhancing technological innovation to achieve a dual-drive mechanism of "financial resources + digital technology." In southern regions, where the digital economy is more advanced, policies should guide digital capital toward green investments, accelerating the application of digital tools in risk assessment, project selection, and monitoring. Coordinated regional strategies and knowledge exchange can help form a nationwide synergy between green finance and the digital economy, fostering balanced and sustainable development.

4)Promote Digital Infrastructure Development and Innovate Green Finance Supervision: As green finance and the digital economy converge, it is critical to strengthen data security, information disclosure, and intelligent supervision systems. Establishing cross-departmental and cross-regional data-sharing mechanisms and implementing financial technology regulatory sandboxes can improve the efficiency of matching financial technology solutions with green projects, reduce market entry barriers, and facilitate the efficient flow and risk diversification of green capital. This will create a resilient and transparent environment in which digital technology actively supports sustainable finance growth.

In sum, these policy recommendations aim to cultivate a mutually reinforcing relationship between green finance and the digital economy, ensuring that both systems contribute to China's long-term sustainable development, regional coordination, and innovation-driven growth.

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