JSSI

Journal of Social Science Innovation

***JSSI*, Vol. 1, No. 1, 2026, pp.39-57**

Print ISSN: 3134-9226; Online ISSN: 3134-9234

Journal homepage: https://www.ssijournal.com

DOI: Https://doi.org/10.64058/jssi260104sssbi

HIEP
Academic Publishing

Stepping Stones or Stumbling Blocks? The Impacts of Digital Finance on Urban Green Development

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Abstract: Using data from 301 Chinese cities (2011-2021), this study empirically explores digital finance's impact on urban green development. Findings show digital finance's promotional effect—validated by endogeneity checks—is more pronounced in non-coastal and the third level cities. Decomposition regression reveals digital payment, insurance, and investment significantly boost green development, while digital credit hinders it. Moderating effect tests indicate green finance positively moderates the relationship, whereas resource endowments exert a negative moderating impact. Threshold effect analysis shows digital finance's effect is insignificant for cities with below-threshold innovation capacity (digital credit even harms green development), but both digital finance and credit drive it significantly for cities above the threshold. Non-linear analysis finds digital credit has an inverted U-shaped impact (initial promotion, subsequent hindrance), mediated by enhanced green innovation and alleviated financing constraints. Overall, digital finance, green finance's positive moderation, and sufficient regional innovation act as "stepping stones," while excessive digital credit, resource endowments' negative moderation, and insufficient innovation are "stumbling blocks." The conclusions inform inclusive digital finance development, high-quality economic growth, and ecological protection.

Keywords: digital finance; green development; "inverted U-shaped" effect

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Received: 6 Jan 2026 / Revised: 19 Apr 2026 / Accepted: 23 Apr 2026 / Published online: 30 Apr 2026 / Print published: 30 May 2026.

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标题：垫脚石还是绊脚石？数字金融对城市绿色发展的影响

摘要：本文基于 2011-2021 年中国 301 个城市的数据，实证考察了数字金融对城市绿色发展的影响。研究结果显示：经内生性检验验证，数字金融对绿色发展具有促进作用，且该效应在非沿海地区及第三类城市中更为显著。分解回归表明，数字支付、数字保险与数字投资均能显著推动绿色发展，而数字信贷则对其产生抑制作用。调节效应检验显示，绿色金融在二者关系中发挥正向调节作用，而资源禀赋则存在负向调节效应。门槛效应分析发现：对于创新能力低于门槛值的城市，数字金融的影响并不显著，且数字信贷甚至会损害绿色发展；而当城市创新能力跨越门槛值后，数字金融与数字信贷均能显著驱动绿色发展。非线性分析表明，数字信贷对绿色发展存在先促进、后抑制的倒 U 型影响，其机制为绿色创新与缓解融资约束的中介效应。总体而言，数字金融、绿色金融的正向调节以及充足的区域创新能力是绿色发展的“垫脚石”；而过度的数字信贷、资源禀赋的负向调节与创新能力不足则是“绊脚石”。本文结论为普惠数字金融发展、经济高质量增长与生态环境保护提供了参考。

关键词：数字金融；绿色发展；“倒 U 型影响”

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1. Introduction

Green development refers to sustainable development that achieves the goals of low pollution and high output without sacrificing the environment (Angang, 2011), emphasizing the balanced development of ecology, economy, and society. Among various influencing factors, financial development has always played a crucial role. On the one hand, financial development exerts effects of efficiency improvement and transformation promotion. It channels capital from low-efficiency sectors to high-efficiency ones, thereby enhancing capital allocation efficiency (Greenwood & Jovanovic, 1990). Meanwhile, it drives the development of strategic emerging industries and facilitates the green transformation of the economy (Zhang & Chen, 2021). On the other hand, financial development has a pollution expansion effect. In terms of production, a higher proportion of total credit—especially a higher proportion of private sector credit—leads to increased pollutant emissions by enterprises (Ju et al., 2023), which is particularly prominent in emerging and developing countries (Jiang

& Ma, 2019). In terms of consumption, financial development eases consumption constraints, enabling consumers to purchase large household appliances more easily (Sadorsky, 2010), thereby increasing carbon dioxide emissions (Zhang, 2011).

The development of digital finance has not only injected new impetus into the development of the entire financial industry. Digital finance generally refers to the business model in which traditional financial institutions and internet companies leverage digital technologies to conduct financing, payment, investment, and other emerging financial activities (Huang & Huang, 2018). During the three phases of 2013-2016, 2017-2019, and 2020-2022, China's digital finance has experienced explosive growth, stable and moderate growth, and a burgeoning phase of rapid development respectively (Li & Zhang, 2024). The advancement of digital finance has reduced information asymmetry and costs, helping small and medium-sized enterprises (SMEs) and state-owned enterprises (SOEs)—especially large-scale SOEs—address financing constraints (Han et al., 2023).

Digital finance has brought new opportunities for urban green development. It reduces pollutant emissions by alleviating financing constraints (Wei et al., 2023), promoting the adjustment and upgrading of industrial structure (Wang & Fan, 2022), driving technological innovation (Zhuang et al., 2022) , and advocating environmental protection concepts; enhances urban ecological resilience by improving resource utilization efficiency and facilitating green investment (Zhao et al., 2024); and promotes pollution and carbon reduction in local and adjacent regions by raising the level of green financing and green innovation (Luo et al., 2024).

Some studies have also found that digital finance exerts non-linear impacts on carbon emissions at different levels. First, digital finance has an "inverted U-shaped" impact on carbon emissions across China's provinces, cities, and enterprises: it exerts an "inverted U-shaped" impact on enterprises' carbon emission intensity through scale expansion and changes in energy efficiency; it produces an "inverted U-shaped" impact on provincial carbon emissions via the output-increasing effect and energy-saving effect; and it generates an "inverted U-shaped" impact on urban carbon dioxide emissions through the superimposed effect of the emission-promoting effect from economic scale expansion and the emission-reducing effect from green technological innovation. Second, although digital finance exerts a significant overall inhibitory effect on provincial carbon emissions, when digital finance or urbanization is taken as the threshold variable, a "fluctuating" impact—characterized by initial inhibition, subsequent promotion, and then re-inhibition—emerges (Wang & Yin, 2022). Third, research using Python machine learning models has revealed that digital finance has a U-shaped-like impact on urban carbon emissions: when the development level of digital finance reaches 200, the efficiency of promoting carbon emission reduction hits a bottleneck; beyond 200, the advancement of digital finance instead increases carbon emissions (Wang et al., 2022).

Scholars have conducted relatively comprehensive research on the green economic effects of digital finance and achieved abundant research outcomes. Most studies affirm the contribution of digital finance to

carbon emission reduction, arguing that its development reduces carbon emissions by alleviating financing constraints, promoting industrial agglomeration and technological innovation, and improving production efficiency and energy use efficiency. These findings provide a certain theoretical basis for this paper, but there are still aspects worthy of improvement. First, most literatures take carbon emissions as the explained variable without considering the overall economic development. Such research, which "focuses solely on 'greenness' while neglecting 'development'", severs the connection between the output-increasing effect and the emission-reducing effect, and ignores the synergistic development relationship between economic growth and environmental protection. Second, most studies on regional analysis are conducted from a provincial perspective, lacking in-depth analysis from the perspective of prefecture-level cities. Third, there is no comprehensive analysis of the impact of digital finance on urban green development from a mechanistic perspective, and the differences in impacts generated by different sub-businesses of digital finance are overlooked. Fourth, most literatures focus on studying the promotional effect of digital finance on carbon emission reduction and energy use efficiency, but fail to analyze whether it has negative impacts or non-linear impacts on urban green development. Fifth, the moderating effect of digital finance on urban green development has not been accurately captured, and targeted policy recommendations have not been proposed.

Based on this, this study utilizes panel data of 301 cities in China from 2011 to 2021 to empirically examine the impact of digital finance on urban green development, and conducts a series of robustness tests, mechanism tests, heterogeneity analysis, decomposition regression, moderating effect tests, and threshold effect tests. The potential marginal contributions are as follows: (1) This study adopts urban green GDP as the measurement indicator for urban green development, organically unifying economic growth and environmental protection. (2) It systematically analyzes the impact of digital finance on the green development of 301 cities, filling the research gap at the urban level. (3) It elaborates on the impacts and moderating effects of various sub-indicators of digital finance on urban green development. (4) It comprehensively examines the threshold effects of digital finance and its sub-indicator—digital credit—on urban green development, and explores the impact of the innovation capacity threshold. (5) It conducts an exploratory analysis of the non-linear impacts of digital finance on urban green development and the underlying mechanisms of such impacts.

2. Data, methodology and model

Based on data availability, this paper selects 301 Chinese cities from 2011 to 2021 as the observation sample.[1] The dependent variable is Green GDP (GGDP), and the independent variable is Digital Finance (DF). The control variables are R&D Level (RD), Per Capita Income (PGDP), Level Of Openness (Open) and Infrastructure Construction (IC). Moderating variables are Green Finance (GF) and Resource Endowment (RE). The threshold variable is regional innovation (RI). The mechanism variables in the parabolic model are Green Innovation (GE) and financing constraints (FC). The data details are given by Table 1.

[1] Including municipalities, non-municipal cities, autonomous prefectures, etc.

Indicator	Calculation Method	Data Source
Green GDP (GGDP)	(Real GDP) / (Comprehensive Pollution Index[1])	China City Statistical Yearbook China Environmental Statistics Yearbook
Digital Finance (DF)		Peking University Digital Inclusive Finance Index (2011–2022)
R&D Level (RD)	$\frac{\text{R\&D Expenditure}}{GDP}$	China City Statistical Yearbook
Per Capita Income (PGDP)	$Ln(1+PerGDP)$	
Level Of Openness (Open)	$\frac{FDI}{GDP}$	
Infrastructure Construction (IC)	$ln\,(1+Passenger\,Traffic\,)$	
Regional Innovation (RI)	Regional Innovation & Entrepreneurship Index	Peking University Business Big Data Research Center
Green Finance (GF)	Comprehensive index obtained using the entropy weight method[2]	National Bureau of Statistics of China, Ministry of Science and Technology, People's Bank of China
Resource Endowment (RE)	$\frac{Mining\ industry\ workers}{Total\ workers}$	China City Statistical Yearbook
Green Innovation (GI)	Number of green patents applied for per 10,000 people	CNRDS
Financing Constraints (FC)	Loan/GDP	China City Statistical Yearbook

Table 1: Data Description

In order to verify the impact of digital finance on urban green development, this paper constructs the following benchmark model：

$$GGDP_{i,t}=\alpha_0+\alpha_1 DF_{i,t}+\alpha_2 Control_{i,t}+\lambda_i+\eta_t+\mu_{i,t} \quad (1)$$

Here in Eq. (1), the dependent variable is $GGDP_{i,t}$, the independent variable is $DF_{i,t}$. The vector $Control_{it}$ represents a series of control variables that affect urban green development； i represents the prefecture-level city, t represents the year; λ_i represents individual fixed effects; η_t represents the time fixed effect; η_t represents the random error term.

[1] Use the entropy weight method to weight wastewater, sulfur dioxide, and smoke, obtaining the comprehensive pollution index.

[2] Green Credit, Green Investment, Green Insurance, Green Bonds, Green Support, Green Funds, And Green Equity

To verify whether digital finance exerts a moderating effect on green development, this paper constructs the moderating effect model as follows：

$$GGDP_{i,t}=\beta_0+\beta_1 DF_{i,t}+\beta_2 adjust_{i,t}+\beta_3 DF_{i,t}\times adjust_{i,t}+\beta_4 Control_{i,t}+\lambda_i+\eta_t+\mu_{i,t} \quad (2)$$

Here in Eq.(2), $adjust_{i,t}$ is the moderating variable, and $DF_{i,t}\times adjust_{i,t}$ is the interaction term between the moderating variable and the explanatory variable. If the coefficient β_3 of the interaction term in the model is significant, it indicates that there is a moderating effect of digital finance on the green development of cities: if β_3 is significant and has the same sign as α_1, it means that the larger the value of the moderating variable, the greater the impact of digital finance on the green development of cities; if β_3 is significant and has the opposite sign to α_1, it means that the larger the value of the moderating variable, the smaller the impact of digital finance on the green development of cities.

Following the methodology of (Hansen, 1999), this study adopts the single threshold model to examine the threshold effect of innovation capability in the impact of digital finance and digital credit on urban green development, and establishes the model as follows:

$$GGDP_{i,t}=\gamma_0+\gamma_1 DF_{i,t}\times I(RI\leq \tau_1)+\gamma_2 DF_{i,t}\times I(RI> \tau_1)+\gamma_3 Control_{i,t}+\lambda_i+\mu_{i,t} \quad (3)$$

Here in Eq.(3), RI is the threshold variable; τ_1 is the threshold value, and $I(\cdot)$ is the indicator function, which takes the value of 1 when the condition is satisfied and 0 when it is not.

To verify whether there is a U-shaped or inverted U-shaped impact, this study constructs the parabolic model as follows:

$$GGDP_{i,t}=\vartheta_0+\vartheta_1 DF_{i,t}+\vartheta_2 (DF_{i,t})^2+\vartheta_3 Control_{i,t}+\lambda_i+\eta_t+\mu_{i,t} \quad (4)$$

Here in Eq.(4), $(DF_{i,t})^2$ is the squared term of digital finance. If $\vartheta_1$and ϑ_2 are significant and of opposite signs, it indicates that there may be a parabolic impact; if the extreme point lies within the valid interval, it means the model passes the U-test and there exists a significant parabolic impact. If $\vartheta_1> 0$ and $\vartheta_2 < 0$, it indicates a U-shaped impact; if $\vartheta_1 < 0$ and $\vartheta_2> 0$, it indicates an inverted U-shaped impact.

To examine the mediating effects of green innovation and financing constraints, and to minimize the endogeneity of mediating variables, this study adopts the two-step method for mediating effects proposed by (Jiang, 2022), by integrating the parabolic model, and establishes the following mediating effect models:

$$mediator_{i,t}=\rho_0+\rho_1 DF_{i,t}+\rho_2 (DF_{i,t})^2+\rho_3 Control_{i,t}+\lambda_i+\eta_t+\mu_{i,t} \quad (5)$$

$$GGDP_{i,t}=\xi_0+\xi_1 mediator_{i,t}+\xi_2 Control_{i,t}+\lambda_i+\eta_t+\mu_{i,t} \quad (6)$$

Here in Eq.(5) and Eq.(6), $mediator_{i,t}$ represents the mediating variable. In the first step of the test, if ρ_1 and ρ_2 in Model (5) are significant, of opposite signs, and pass the U-test, it indicates that digital finance has a significant U-shaped or inverted U-shaped impact on the mediating variable; in the second step, if the coefficient ξ_1 of digital finance in Model (6) is significant, it means there is a correlation between the mediating variable and urban green development, and the mediating effect holds.

3. Results and implications

3.1 Empirical results and discussion

To analyze the impact of digital finance on urban green development, this paper employs the individual-time double fixed effects model for empirical tests, with the regression results presented in Table 2. Column (1) reports the impact of DF on GGDP without control variables. The results show that after controlling for urban fixed effects and year fixed effects, the coefficient of DF is significantly positive, indicating that DF exerts a significant promoting effect on GGDP. Columns (2) to (5) successively incorporate control variables such as the proportion of R&D expenditure, per capita income, level of opening-up, and transportation infrastructure construction. The findings reveal that after the successive inclusion of each control variable, the coefficient of digital finance remains significantly positive, with only a slight variation in its value. Meanwhile, it can be observed that improvements in per capita income, opening-up, and transportation infrastructure also significantly contribute to GGDP. The results across Columns (1) to (5) demonstrate that the promoting effect of digital finance on urban green development passes the significance test at the 1% level.

Variable	GGDP				
	(1)	(2)	(3)	(4)	(5)
DF	0.015***	0.015***	0.012***	0.012***	0.012***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
RD		-0.083	0.162	0.173	0.299
		(0.128)	(0.209)	(0.208)	(0.229)
PGDP			0.389***	0.385***	0.370***
			(0.130)	(0.128)	(0.127)
Open				1.524**	1.563**
				(0.758)	(0.780)
IC					0.062**
					(0.028)
Constant	17.048***	17.033***	13.427***	13.429***	13.115***
	(0.433)	(0.433)	(1.278)	(1.256)	(1.206)
City Fixed	YES	YES	YES	YES	YES
Year Fixed	YES	YES	YES	YES	YES
Observation	2,799	2,798	2,783	2,782	2,732
R^2	0.817	0.817	0.823	0.824	0.826

Table 2: Basic regression

3.2 Endogeneity test

To mitigate the bias potentially caused by endogeneity issues, this paper adopts four different instrumental variables to conduct endogeneity tests. First, to verify the existence of endogeneity arising from reverse causality, this study uses the one-period lag of the digital finance index as the core explanatory variable. Second, to address endogeneity caused by factors such as omitted variables, it refers to the approach of (Xu et al., 2023) and selects the number of internet broadband accesses (per 10,000 people) as the instrumental variable (IV1) for digital finance, conducting a two-stage least squares (2SLS) test. Third, the interaction term between the spherical distance from each city to Hangzhou and the national average of digital inclusive finance is used as another instrumental variable (IV2) for digital finance, with a subsequent 2SLS test. Fourth, leveraging the method of (Hu & Yang, 2023), this paper constructs two interaction terms—one using the number of post offices in 1984 and the number of telephones per 10,000 people, and the other combining these two indicators with the annual number of internet users—to form two additional instrumental variables (IV3 and IV4).

The above instrumental variables are closely associated with urban digital finance while not directly influencing urban green development, thus meeting the requirements for valid instrumental variables. The test results are presented in Table 3.

- Column (1) shows that the coefficient of the one-period lag of digital finance (DF) remains significantly positive, verifying the robustness of the results.

- Columns (2) to (3) indicate that when the number of internet broadband accesses is used as the instrumental variable, the coefficients of IV1 are significantly positive in both the first and second stages.

- Columns (4) to (5) demonstrate that when the interaction term constructed with the spherical distance to Hangzhou is employed as the instrumental variable, the coefficients of IV2 are significantly positive in both stages.

- Columns (6) to (7) reveal that when the interaction terms derived from the 1984 post office number and telephone number are used as variables, the coefficients of IV3 and IV4 are significantly positive in both stages.

Comprehensively analyzing the results from Columns (1) to (7) reveals that the coefficients of the lagged terms of the explanatory variable and all lagged items, as well as the F-statistics, are significant, indicating that the endogeneity test is passed.[1]

[1] The endogeneity tests in this paper have passed the underidentification test, weak instrumental variable test, Hausman endogeneity test, and overidentification test. These tests are omitted due to space constraints and are available upon request.

Variable	GGDP	DF	GGDP	DF	GGDP	DF	GGDP
		Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
	（1）	（2）	（3）	（4）	（5）	（6）	（7）
DF			0.026**		0.024*		0.053***
			(0.012)		(0.014)		(0.015)
Lagged DF	0.012*** (0.003)						
IV1		0.014*** (6.91)					
IV2				-19.299***			
IV3						-249.448*** （-5.70）	
IV4						249.946*** （5.69）	
Constant	13.409*** (1.258)		15.294*** (0.498)	198.411*** (5.65)	14.527*** (0.476)	1045.241*** （5.70）	14.848*** (0.566)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F Test	12.06***		21.12***		32.65***		18.69***
Observation	2,452		2,449		2,714		2,125
R^2	0.834		0.251		0.2643		0.2928

Table 3: Instrumental Variable Endogeneity Test

3.3 Decomposition Regression

The analysis above shows that digital finance exerts a significant promoting effect on urban green development, and this conclusion has passed endogeneity tests. However, digital finance is a comprehensive indicator encompassing multiple services—does each of its sub-indicators contribute to urban green development? To address this question, this paper conducts a decomposition regression: it decomposes digital finance into three dimensions, namely digital finance coverage breadth, usage depth, and digitalization level , and re-performs the regression analysis. The results indicate that the coefficients of coverage breadth, usage depth, and digitalization level are all significantly positive. Among these, digital finance usage depth accounts for 29.7% of the weight in the indicator system and includes 6 key sub-indicators related to consumption and production; thus, an exploratory decomposition regression of digital finance usage depth is further conducted. After decomposing digital finance usage depth into digital payment, digital insurance, digital currency funds, digital investment, digital credit, and digital credit services, the results are presented in Table 4.

Columns (1), (2), and (4) show that the coefficients of digital payment, digital insurance, and digital investment are significantly positive. Possible explanations are as follows: digital payment significantly reduces resource consumption by promoting "cashless" and "paperless" consumption; digital wealth management insurance (such as annuity insurance or participating insurance) prioritizes allocating funds to green bonds, thereby facilitating the development of clean energy.

Columns (3) and (6) reveal that the coefficients of digital currency funds and digital credit services are not significant. Potential reasons include: bank agreement deposits and short-term bonds struggle to form a green capital agglomeration effect; credit services are mostly applied in consumption scenarios, making it difficult to establish a strong connection with green development.

The result in Column (5) is completely contrary to expectations: the coefficient of digital credit is significantly negative, indicating that the development of urban digital credit hinders urban green development. According to existing literature, the improvement of urban credit level eases corporate financing constraints, creating room for enterprises to achieve green transformation in production, management, and sales. However, why does the development of digital credit hinder urban green development? After alleviating financing constraints, both excessive corporate expansion and excessive residential consumption may exert negative impacts on green development. In other words, there may be an "optimal level" of digital credit for urban green development, which necessitates further analysis of the impact of digital credit.

Viriables	GGDP					
	(1)	(2)	(3)	(4)	(5)	(6)
Digital Payment	0.005***					
	(0.001)					
Digital Insurance		0.002***				
		(0.000)				
Digital Currency Fund			0.001			
			(0.002)			
Digital Investment				0.005***		
				(0.001)		
Digital Credit					-0.006***	
					(0.002)	
Digital Credit Investigation						0.000
						(0.001)
Constant	14.103***	14.195***	17.080***	14.847***	15.316***	18.398***
	(1.330)	(1.389)	(1.070)	(1.682)	(1.477)	(1.357)
Control Viriables	Yes	Yes	Yes	Yes	Yes	Yes
City Fixed	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed	Yes	Yes	Yes	Yes	Yes	Yes
Observation	2,732	2,732	1,643	1,895	2,731	1,085
R^2	0.825	0.824	0.850	0.857	0.824	0.864

Table 4: Decomposition Regression of Digital Finance Usage Depth

3.4 Test of Moderating Effect

The previous analysis reveals that the composite index and sub-indicators of digital finance exert both promoting and hindering effects on urban green development. The question then arises: how to amplify the promoting effect of digital finance while mitigating the hindering effect of digital credit? Moderating effect

analysis can be employed to verify the pathways to achieve this. Table 5 presents the moderating effect tests for the impact of digital finance (DF) and digital credit (DC) on urban green development, with green finance (GF) and resource endowment (RE) serving as the moderating variables.

- Column (1) shows that the coefficient of the interaction term (DF×GF) is significantly positive, sharing the same sign as DF and being statistically significant. This indicates that the higher the level of a city's green finance development, the stronger the promoting effect of digital finance on its green development.

- Column (2) reveals that the coefficient of the interaction term (DF×RE) is significantly negative, bearing the opposite sign to DF. This suggests that the stronger a city's resource endowment, the weaker the promoting effect of digital finance on its green development.

- Column (3) demonstrates that the coefficient of the interaction term (DC×GF) is significantly positive, showing the opposite sign to DC and being statistically significant. It implies that the higher the level of a city's green finance development, the weaker the hindering effect of digital credit on its green development.

- Column (4) indicates that the coefficient of the interaction term (DC×RE) is significantly negative, sharing the same sign as DC. This means that the stronger a city's resource endowment, the stronger the hindering effect of digital credit on its green development.

The results from Columns (1) to (4) indicate that: green finance strengthens the promoting effect of digital finance on urban green development and suppresses the hindering effect of digital credit on it; resource endowment weakens the promoting effect of digital finance on urban green development and reinforces the hindering effect of digital credit on it. A plausible explanation is as follows: On the one hand, with the backing of green finance, more loans released by digital finance flow to clean energy enterprises, which enhances the level of regional environmental governance and improves regional environmental quality (Hu et al., 2023), thereby reducing pollution emissions (Cui et al., 2023). On the other hand, the comparative advantage of resource endowment is likely to give rise to a minority rentier class , which gradually renders environmental regulation ineffective, slows down the pace of regional green development, and leads to the "resource curse" effect.

Viriables	GF	RE	GF	RE
	(1)	(2)	(3)	(4)
DF	0.011***	0.009***		
	(0.003)	(0.002)		
DC			-0.236***	-0.004***
			(0.051)	(0.001)
Moderating variable	-0.734**	-0.084	-1.672**	0.146
	(0.334)	(0.541)	(0.807)	(0.427)
Interaction Term	0.003*	-0.005**	0.323**	-0.005**
	(0.002)	(0.002)	(0.163)	(0.003)
Constant	13.372***	14.430***	18.372***	18.134***
	(1.212)	(1.218)	(0.391)	(0.366)
Control Viriables	Yes	Yes	Yes	Yes
City Fixed	Yes	Yes	Yes	Yes
Year Fixed	Yes	Yes	Yes	Yes
Observation	2,732	2,283	2,729	2,278
R^2	0.827	0.832	0.821	0.828

Tabel 5: The Moderating Effect of Green Finance and Resource Endowment

4. Further research: Nonlinear effect

4.1. Threshold Effect Test

From the above analysis, it can be seen that moderating effects can be used to amplify promoting effects and reduce hindering effects. However, do these promoting and hindering effects only exist in certain stages of urban development? In fact, digital finance may exert different impacts on urban green development in different stages of regional innovation capability development. Enterprises' green transformation not only requires sufficient funds provided by digital finance but also relies on the innovation capability of their respective regions as a foundation.

In the stage of low regional innovation capability, digital finance struggles to drive urban green development due to factors such as high costs for new enterprises, a small number of high-quality foreign-funded enterprises, limited access to venture capital, and weak technological advantages. After regional innovation capability reaches a certain level, digital finance can effectively promote green development, thanks to a significant reduction in the cost of new enterprises, an increase in advanced management experience, more venture capital opportunities, and the expansion of regional technological advantages.

To verify this, this paper employs the Bootstrap method to test whether there is a threshold effect of regional innovation (RI) on the impact of digital finance (DF) and digital credit (DC) on urban green development. The results in Column (1) of Table 6 show that when digital finance is the explanatory variable, regional innovation passes the single threshold effect test at the 1% significance level, with a threshold value of 45.392. The results in Column (2) show that when digital credit is the explanatory variable, regional innovation capability also passes the single threshold effect test at the 1% significance level, with the same threshold value of 45.392. Therefore, based on the results of the threshold effect test, this paper selects the single threshold model to study the threshold effect of digital finance on urban green development. [1]

	Single-Threshold Model	Single-Threshold Model
	(1)	(2)
Explanatory Variable	DF	DC
Threshold Variable	RI	RI
Threshold Value	45.392***	45.392***
	(31.03)	(31.53)
95% Confidence Interval	[41.638,47.270]	[41.638, 47.270]

Table 6: Threshold Effect Test

The results in Columns (1) to (2) of Table 7 show that the impact of digital finance (DF) on urban green development exhibits a threshold effect: when regional innovation (RI) is less than or equal to 45.392, the coefficient of DF on urban green development is approximately 0 and statistically insignificant; when regional innovation exceeds 45.392, the coefficient of DF on urban green development is approximately 0.001 and

[1] Furthermore, this paper also conducted tests on the double threshold model and triple threshold model, and the significance of their thresholds and interval coefficients is lower than that of the single threshold model.

passes the significance test at the 1% level. The results in Columns (3) to (4) indicate that the impact of digital credit (DC) on urban green development also presents a threshold effect: when regional innovation is less than or equal to 45.392, the coefficient of DC on urban green development is approximately -0.001 and passes the significance test at the 5% level; when regional innovation exceeds 45.392, the coefficient of DC on urban green development is approximately 0.001 and passes the significance test at the 5% level.

Synthesizing the results from Columns (1) to (4), it is found that when regional innovation is less than or equal to the threshold value, the impact of digital finance on urban green development is insignificant, and even its sub-indicator—digital credit—exerts a hindering effect on urban green development. When regional innovation is higher than the threshold value, both digital finance and digital credit significantly promote urban green development.

This result suggests that the promoting effect of digital finance on urban green development requires a certain level of regional innovation as a foundation. The possible explanation for this is that the stage of low regional innovation is often accompanied by high innovation costs; therefore, enterprises fail to allocate the funds released by digital finance to the green transformation of production processes, pollution treatment, and other links. Some enterprises even only use the funds released by digital credit to expand production scale, which instead hinders urban green development. Only when regional innovation reaches a certain level, enterprise innovation costs are lower, so enterprises have the incentive to allocate the funds released by digital finance to green transformation, thereby promoting urban green development.

Explanatory variable: DF		Explanatory variable: DC	
Range/Variable	Coefficient	Range/Variable	Coefficient
（1）	（2）	（3）	（4）
RI≤45.392	0.000	RI≤45.392	-0.001**
	(0.000)		(0.000)
RI >45.392	0.001***	RI >45.392	0.001**
	(0.000)		(0.000)
Constant	17.374***	Constant	19.680***
	(0.825)		(0.044)
Observations	2,484	Observations	2,484
R^2	0.033	R^2	0.014

Tabel 7: Threshold Model Estimation Results

4.2. U-shaped effect test

The previous analysis found that although digital finance exerts an overall promoting effect on urban green development, its impact is not necessarily linear, and there may be an “optimal level of digital finance”. To verify whether digital finance has a non-linear impact on urban green development, this paper linearly standardized both the explanatory variable and the explained variable, and then conducted a non-linear test incorporating the quadratic term of digital finance (DF).

The results in Column (1) of Table 8 show that the coefficient of the quadratic term of DF is significantly negative, while the coefficient of the linear term of DF is significantly positive. The slope changes from negative to positive, the extreme point falls within the interval, and the U-test is passed significantly. Thus, there exists a significant "inverted U-shaped" curve. A possible explanation is as follows: In the early stage of digital finance development, on the one hand, the enabling effect of digital technology on finance reduces "financial discrimination" against private enterprises and micro, small, and medium-sized enterprises (MSMEs), improves regional financial allocation efficiency, alleviates financing constraints on technological innovation, and promotes the transformation of industrial structure from labor and capital-intensive to knowledge-intensive, thereby boosting urban green development. On the other hand, financial tools such as Huabei, Jingdong Baitiao, and WeChat Baitiao greatly ease household consumption constraints, stimulate household consumption, and household consumption drives per capita real income through the multiplier effect, reducing pressure from environmental pollution and promoting urban green development (Grossman & Krueger, 1991). In the late stage of digital finance development, on the one hand, the urban industrial structure adjustment process has been completed, and credit funds are more used to expand industrial scale. During the expansion of industrial scale, the marginal effect of technological innovation diminishes, and the growth rate of energy consumption and pollutant emissions exceeds that of industrial output, thus hindering urban green development. On the other hand, excessive consumption caused by personal consumer loans leads to excessive consumption-related pollution, resulting in the continuous accumulation of domestic waste such as plastics and worsening environmental pollution(Cai et al., 2022).

When the regression results are plotted as a parabola, Figure 1 is obtained. This figure shows that there is an "optimal level of digital finance": when the currently standardized DF is 0.516, urban green development reaches a peak.

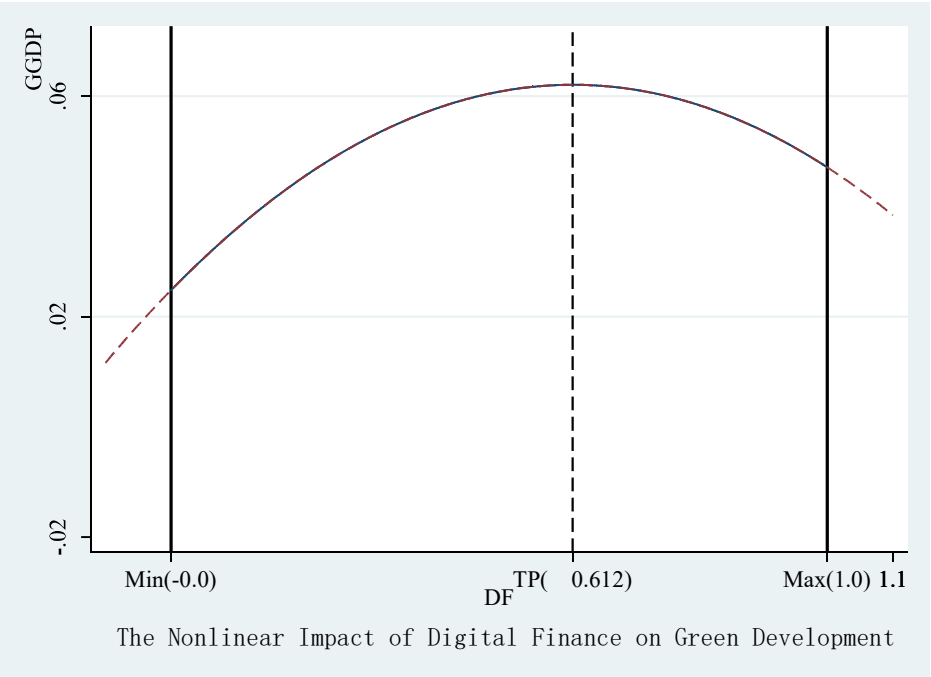

Figure 1: Nonlinear Impact of Digital Finance on Urban Green Development

What is intriguing is that what factors contribute to this "inverted U-shaped" impact? To explore the mechanism of this nonlinear impact, this paper conducts mediating effect tests for green innovation (GI) and financing constraints (FC).

Column (2) of Table 8 shows that digital finance (DF) exerts a significant "inverted U-shaped" impact on green innovation and passes the U-test. Column (3) reveals that green innovation is significantly positively correlated with GGDP. The results in Columns (2) to (3) indicate that digital finance achieves its "inverted U-shaped" impact on urban green development by exerting a first-promoting-then-impeding effect on green innovation. Column (4) shows that digital finance has a significant "U-shaped" impact on financing constraints. Column (5) demonstrates that financing constraints are significantly negatively correlated with GGDP. The results in Columns (4) to (5) suggest that digital finance realizes its "inverted U-shaped" impact on urban green development by first reducing and then increasing financing constraints.

The possible reasons behind the results in Columns (2) to (5) are as follows: In the early stage of digital finance development, financial institutions optimize risk control and alleviate financing constraints, enabling funds to accurately match the financing needs of green projects, promoting corporate green innovation, and thereby driving urban green development. After the scale of digital finance exceeds the critical point, the growth rate of lending outpaces that of financial supervision, leading to funds flowing into short-term high-yield areas, causing resource misallocation, exacerbating financing constraints, and leaving green innovation without sufficient financial support—this in turn hinders urban green development.

Variables	GGDP	GI	GGDP	FC	GGDP
	(1)	(2)	(3)	(4)	(5)
$(DF_{i,t})^2$	-0.104**	-0.118***		0.234***	
	(0.050)	(0.021)		(0.057)	
$DF_{i,t}$	0.108**	0.107***		-0.215***	
	(0.048)	(0.021)		(0.056)	
GI			0.087***		
			(0.029)		
FC					-0.053***
					(0.012)
Constant	-0.191***	0.057*	-0.181***	0.531***	-0.156***
	(0.066)	(0.031)	(0.049)	(0.080)	(0.048)
U-TEST	Yes	Yes		Yes	
extreme point	0.516	0.453		0.459	
Range	[0,1]	[0,1]		[0,1]	
Slope	[0.108,-0.101]	[0.107,0.129]		[-0.215,0.252]	
Conclusion	Inverted U-shape	Inverted U-shape		U-shape	
Control Viriables	Yes	Yes	Yes	Yes	Yes
City Fixed	Yes	Yes	Yes	Yes	Yes
Year Fixed	Yes	Yes	Yes	Yes	Yes
Observation	2,782	2,529	4,093	2,802	4,391
R^2	0.684	0.946	0.665	0.758	0.645

Table 8: Benchmark Regression of Nonlinear Effects and Mechanism Effects

5. Conclusion

Based on data from 301 prefecture-level cities in China from 2011 to 2021, this paper analyzes a series of impacts of digital finance on urban green development. The study finds that although digital finance can promote urban green development, its impact is not linear. (1) The composite index of digital finance exerts a significant promoting effect on urban green development, which has passed endogeneity tests. (2) Different sub-indicators of digital finance have varying impacts on urban green development: digital payment, digital insurance, and digital investment show significant promoting effects, while digital credit has a significant hindering effect. (3) Green finance amplifies the promoting effect of digital finance and weakens the hindering effect of digital credit; resource endowment weakens the promoting effect of digital finance and amplifies the hindering effect of digital credit. (4) There exists a threshold effect in the model: for cities with innovation capability exceeding the threshold, both digital finance and digital credit can significantly promote urban green development; for cities with innovation capability below the threshold, the impact of digital finance on urban green development is insignificant, and digital credit even has a significant negative effect on urban green development. (5) Digital finance has an "inverted U-shaped" impact on urban green development, with the mechanism being that it promotes green innovation and reduces financing constraints in the early stage of development, while hindering green innovation and exacerbating financing constraints in the later stage.

Based on the conclusions and the current status of digital finance development, this paper puts forward the following suggestions:

First, continuously deepen the development of digital finance to give full play to its role in promoting green development. Establish financial data centers, build high-speed and secure financial network communication systems and new computing power systems, improve the information integration capabilities of financial institutions, form more accurate "user profiles," and enhance financial risk prevention and control capabilities; vigorously cultivate and reserve professional talent teams in financial technology, improve the digital service capabilities of financial institutions to meet the financing needs of core user groups; set up special funds for digital inclusive finance to support cities in applying for national-level digital inclusive finance pilot zones, and encourage enterprises to implement green process innovation and product innovation; accelerate the construction of digital financial infrastructure in rural and remote areas, reduce the "digital divide" between cities at different development levels, further improve the coverage breadth, usage depth, and digitalization level of digital finance, and enhance its inclusiveness; improve the digital financial service system, launch targeted digital financial products, and promote environmental protection concepts such as green travel and green consumption.

Second, actively promote regional innovation and adopt differentiated development strategies based on urban development conditions to better leverage the promoting effect of digital finance. On the one hand, continuously improve the intellectual property system, implement policies for the transformation of scientific and technological achievements and the identification of high-tech technologies, steadily advance the development of technology business incubators, increase support for scientific research innovation,

technological development, and talent introduction, promote collaborative innovation among universities, research institutes, and enterprises, drive high-level development of regional technological innovation, lead more cities to cross the "innovation threshold," and release the promoting effect of digital finance on urban green development. On the other hand, based on differences in natural resource endowments, talent endowments, and technological innovation efforts among different cities, promote cooperation between financial regulatory authorities and research institutions to build real-time monitoring systems and risk early warning systems for urban digital credit scales using big data and intelligent analysis; by setting optimal ranges for digital credit, promptly release early warning information to help local financial institutions adjust credit scales, implement appropriately tight interest rate policies in regions with excessive credit expansion, and relatively loose interest rate policies in regions with insufficient credit, thereby reducing the inhibitory effect of excessive credit expansion on green development.

Third, improve the regional green finance mechanism to guide the orderly, leapfrog, and transformational development of resource-based cities. (1) Give full play to the positive regulatory role of green finance in digital finance, establish priority approval mechanisms for green projects, continuously promote the innovation of financial instruments such as green investment and green funds, and steadily reduce the financing costs of green and low-carbon projects; set "environmental thresholds" for financing of heavily polluting enterprises such as chemical and building materials enterprises, and design clean technology transformation plans in combination with regional characteristics to direct more digital financial resources to green fields such as environmental protection and clean energy; strengthen the joint supervision of green finance and digital credit, formulate green finance guidelines for consumer loans and operating loans, expand the scope of green consumption and green operations, ensure that the flow of digital credit funds is in line with the overall goals of green finance, and reduce the negative impact of excessive lending on urban green development. (2) Promote the digital transformation of financial institutions in resource-based cities, use digital finance to drive the application of green technologies in resource-based industries, encourage financial institutions to allocate more funds to green projects using digital technologies such as big data and artificial intelligence, provide tax reductions or loan interest subsidies for projects in fields such as ecological restoration and clean energy, reduce excessive dependence on natural resources, and weaken the negative regulatory effect of resource endowment on digital finance.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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