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Original Research

A Study on the Impact of Digital Finance on the Efficiency of Urban Green Economy Development

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Abstract

In this study, we analyze panel data from 285 Chinese cities at the prefectural level or above for the period 2011 to 2019 to empirically investigate how digital finance influences the efficiency of green economic development using the GML score within the SBM model. The study revealed a significant enhancement in the efficiency of urban green economic growth through the utilization of digital financing. Furthermore, the article offers additional evidence that the efficiency of urban green economies is enhanced by the innovative impact of digital finance. The findings of this research suggest that for the promotion of green innovation and the enhancement of urban green innovation effectiveness, China should focus on strengthening its digital infrastructure, facilitating the growth of regional digital inclusive finance, and establishing a diverse digital inclusive finance system.

Keywords: digital finance, green economy, SBM model, GML index

Introduction

Facing energy crises, global warming, and pressures on resources and the environment, governments worldwide are actively pursuing sustainable economic development. A green economy, which is characterized by resource conservation and environmental friendliness, has become a global consensus and a national strategic imperative [1].

China's economy has made significant progress over the past four decades of reform and opening up. However, the country's historical, unplanned growth approach has led to the extensive utilization of resources and the depletion of natural spaces [2]. The current focus on environmental issues, in particular, has drawn the government and the general public's attention to the concept of sustainable economic growth [3]. Balancing economic growth with environmental protection, resource conservation, and fostering China's green economic development has emerged as a challenge for the government [4].

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The financial system serves as the core of any nation or region's economy. Establishing an inclusive, modern financial system characterized by flexibility and competitiveness is a pivotal component in propelling China's high-quality economic growth [5]. Nevertheless, China's conventional financial system faces evident structural challenges, such as the mismatch between the financing model and financial supply. This issue has resulted in widespread difficulties and high costs associated with funding for small, medium, and micro enterprises, limiting the growth of their technological innovation endeavors [6]. Consequently, rectifying the resource mismatch and redirecting additional resources toward the green development sector is not only a crucial imperative for the financial industry to reestablish its foundation and support the real economy but also its ethical obligation.

The quiet evolution of digital inclusive finance is a direct outcome of continuous technological advancements such as artificial intelligence, mobile communication, and blockchain [7]. Digital finance represents a novel financial paradigm in which both traditional financial institutions and internet startups leverage digital technology for various purposes, including payments, investments, financing, insurance, and other financial services [8]. Essentially, it harnesses digital technology to migrate traditional financial services online, serving as a significant illustration of environmentally-friendly transactions [9]. Moreover, the advantages of digital finance, including cost-effectiveness, high efficiency, and extensive accessibility, have transcended the limits of enterprise capital constraints. This has invigorated innovation at the micro-level, created fresh avenues for addressing the financing needs of small and medium-sized enterprises, fueled entrepreneurial growth, and offered substantial support for the advancement of regional green economies [10].

Scholars have conducted numerous studies on the financial mechanisms influencing corporate green innovation. While there's a growing consensus regarding the importance of finance in driving green development [11], there remains a limited exploration of the impact of digital finance on the growth of urban green economies. Traditional finance frequently encounters challenges like information asymmetry and financial frictions arising from incomplete contracts while facilitating the transformation and enhancement of local economies. These challenges significantly hinder the efficient allocation of financial resources to support green economies. Digital finance leverages technologies like big data and cloud computing to accelerate the development of financial products and processes. This approach enhances the likelihood of aligning money supply and demand while fulfilling financing needs in a diverse and personalized manner [12]. Can digital finance significantly contribute to the development of China's urban green economy? If so, what processes underlie the extent and depth of digital finance's impact on China's urban green economy? Is digital finance's contribution to the growth of China's urban green economy multifaceted? These questions demand rigorous and scientific examination. Within this context, a comprehensive assessment of how digital finance drives the growth of urban green economies is vital for shaping future policies related to digital inclusive finance.

This paper's contributions to the existing literature are as follows: Firstly, it offers an in-depth analysis of the underlying mechanism of digital finance-enabled green economy development in China. It elucidates the pathway through which digital finance influences green economy development and supports this analysis with empirical evidence. Secondly, the paper adopts a relatively micro-level research perspective by focusing on Chinese cities at the prefecture level and above. Lastly, we present a viable roadmap for the establishment of a digital finance-enabled green economy in China, drawing upon empirical findings. Additionally, we provide policy and practical recommendations.

The remainder of the paper is structured as follows: Section 2 presents a literature review. Section 3 provides a concise overview of the paper's research hypotheses, data, variable selection, and the empirical econometric model used. In the fourth part, we present the results of a benchmark regression analyzing the impact of digital finance on the growth of the green economy, along with a heterogeneity analysis. Section 5 concludes the paper with key findings and policy recommendations.

Literature Review

Digital finance emerges from the integration of financial services with digital technologies, encompassing the Internet, big data, distributed technologies, artificial intelligence, and information security. It represents a spectrum of financial innovation concepts rooted in Internet finance and financial technology, characterized by the provision of inclusive and precise financial services. According to Huang and Tao [13], their examination of China's digital finance sector reveals that it plays a vital role in enhancing financial efficiency, spurring innovation, promoting inclusive finance, and achieving social equity, among other outcomes. China's growth in this sector not only distinguishes itself from international fintech businesses in terms of business models and platform ecosystems but, more significantly, reflects the maturity of Chinese digital finance. In addition to these distinctions, Chinese digital finance exhibits a higher degree of inclusivity and embodies the fundamental characteristics and values of digital finance. This orientation is beneficial for its role in serving the real economy, particularly in advancing healthy and sustainable economic development. This role becomes evident through various means, including bridging the wealth disparity among urban, rural, and regional areas [14, 15], fostering inclusive growth

[16], stimulating innovation and entrepreneurship [17], and supporting green development [18].

Digital finance can enhance the efficiency and quality of economic development by extending the reach of financial services, enhancing their efficiency, optimizing financial resource allocation, fostering enterprise innovation and growth, and promoting industrial structural upgrades [19]. Lin [20] further emphasizes that increasing the share of direct financing, expanding the scale of financial operations, enhancing financial efficiency, deepening financial market reforms, and raising the direct financing ratio can effectively drive industrial upgrading. This, in turn, promotes China's industrial shift toward green transformation. The size, technology, and structural implications of green finance all play significant roles in the context of the low-carbon economy. These include addressing capital mismatches, encouraging green technology innovation, and optimizing industrial structures. The positive impact of green finance on the low-carbon economy is most pronounced at the lower end of the scale, where severe capital mismatches and weak industrial structures exist, leading to amplified scale and structural effects. The stable and essential contribution of green finance to the low-carbon economy primarily occurs through technological advancements. In the long run, green technological innovation is pivotal for advancing the development of a low-carbon economy [21].

Guo et al. [22] define digital financial breadth as the degree to which users can access suitable services, indicating the breadth of digital finance's user base. Meanwhile, digital financial depth signifies the range of financial services utilized by users, reflecting digital finance's capacity to address users' financial requirements. Digital finance coverage width is determined by the widespread use of the Internet and mobile Internet for establishing electronic accounts. This eliminates temporal and spatial limitations, extending the accessibility of financial services. A broader usage breadth results in a higher number of served entities. The breadth of digital financial usage corresponds to the range of available services, encompassing payment services, money fund services, credit services, insurance services, investment services, and credit services [5, 23].

Prior research has assessed the efficiency of green economies and investigated the factors that impact green economy efficiency, including policies related to new energy, environmental regulations, investments in science and technology, industrial clustering, environmental variables, urban land development intensity, and more [24-26]. Luo [27] suggests that the digital economy enhances the efficiency of green development. The efficiency of green innovation in industrial enterprises exhibits substantial variation across China's eight economic zones [28]. Liu et al. [29] examined the coordination and interrelation between green finance and the green economy by employing a comprehensive index system and an integrated approach. The study's results indicate that provincial coupling coordination degrees are steadily on the rise, with most regions in China now demonstrating only marginal synchronization. On the whole, the level of collaboration between green finance and the green economy exhibits significant regional dependence. Some areas display clustering characteristics of high-high and low-low coordination. Green finance shows pronounced geographical agglomeration, and it maintains a consistent positive spatial association with economic ecological development. Furthermore, the development of green finance not only contributes to the economic and ecological growth within a province but also stimulates the economic and ecological development of neighboring provinces [30].

Research Framework and Methods

Model Building

This econometric model, which explores the impact of digital finance on the efficiency of the green economy, is developed in line with the theoretical insights derived from the preceding analysis.

$$y_{it} = \beta_0 + \beta_1 \text{ DigitalF}_{it} + \beta_2 \text{ control}_{it} + u_i + \varepsilon_{it} \quad (1)$$

Where, y_{it} presents the green economic efficiency of city i in year t, Digital F_{it} represents the level of digital financial development in the sample city, $control_{it}$ denotes the control variables related to urbanization and economic development, u_{it} represents individual fixed effects, and ε_{it} represents random disturbance terms.

Variable Setting

Explained Variables

Green Economic Efficiency (GEE)

In this study, we employ green economic efficiency (GEE) as an independent variable to assess the economic output efficiency, regional economic growth, and developmental quality of Chinese cities within the context of environmental limitations and the imperatives of ecological civilization. To determine GEE, we utilize a global covariate data envelopment analysis framework, the non-expected output super-efficiency (SBM) model, and the Malmquist productivity index. We calculate the GEE scores for 285 Chinese cities (excluding those with significant data deficiencies). Green economic efficiency in each city is assessed using the following parameters.

Input Indicators

The input indicators encompass three secondary measures: labor input, energy input, and capital input.

The labor input indicator is calculated based on the total number of employees in the secondary and tertiary industries within the sample cities. The energy resources input indicator is derived from the cumulative electricity consumption and water supply in the sample cities. The capital input indicator is determined using the following formula: This study adopts a research approach rooted in the perpetual inventory method.

$$K_t = \frac{I_t}{p_t} + (1-\gamma_t) K_{t-1} \quad (2)$$

Calculation of a city's fixed capital stock in period t. Finally, the relevant statistics are corrected using 2005 as the baseline year.

Desired Output

In this paper, economic output (urban GDP) is used as a measure.

Non-Desired Output

In this paper, total industrial wastewater emissions, total industrial SO_2 emissions, total industrial soot emissions, and CO_2 emissions are selected to measure in the sample cities.

Digital Finance

The Peking University Digital Inclusive Finance Index (2011-2019) is a comprehensive dataset jointly compiled by the Peking University Digital Finance Research Centre and Ant Financial Services Group. It provides a comprehensive reflection of the development of digital inclusive finance in Chinese cities. The index is constructed using data from Ant Financial Services Group and encompasses a set of indicators. It is widely employed in relevant research due to its foundation on Ant Financial Group's data and the inclusion of three primary indicators: breadth of coverage, depth of usage, and the degree of digital support services. Acknowledging that the use of a single indicator may not entirely and accurately capture the multifaceted nature of digital inclusive finance, this paper utilizes the overall digital inclusive finance index to gauge the level of digital inclusive finance development in each city. Additionally, it considers the breadth of coverage, depth of usage, and degree of digitalization to assess the performance of digital inclusive finance from multiple perspectives.

Control Variables

To more accurately depict the impact of digital finance on urban green economy efficiency, this article selects the following indicators based on current research and economic and social realities: urbanization level, defined as the ratio of urban population to total population; financial development level, assessed as the percentage of regional GDP represented by the total RMB deposit and loan balances of banking financial institutions in each area; economic development, quantified by the logarithm of regional GDP per capita; government financial expenditure, measured by the logarithm of government spending on science and technology per capita; and human capital, gauged by the proportion of students enrolled in general higher education institutions relative to the total urban population.

Data Sources

Data indicators for this research spanning from 2011 to 2019 were compiled using the 2011-2019 China City Statistics Yearbook, government work reports, statistical bulletins for each city in each year, and the Peking University Digital Inclusive Finance Index. However, due to the unavailability of the fixed asset price index in city statistics yearbooks and bulletins beyond 2019,

Table 1. Descriptive statistics of the main variables.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
GEE	2396	1.1310	0.9145	0.1724	15.9896
Index	2498	5.0006	0.5090	3.5249	5.6522
Breadth	2498	4.9298	0.5415	3.1140	5.6338
Depth	2498	4.9877	0.5021	3.5058	5.6641
Digitization	2498	5.1671	0.6044	3.0160	5.7439
Urban	2209	0.3610	0.2344	0.0625	1.0000
Finance	2458	2.3832	1.0744	0.9868	6.7214
PGDP	2431	10.6789	0.5635	9.4069	12.0615
Fiscal	2458	0.1997	0.1019	0.0439	0.9155
Education	2468	195.8232	224.5307	2.0000	1310.7450

this research is constrained to data up to 2019. In cases of limited data, the mean approach was employed to impute missing data points for the remaining indicators. Descriptive statistics for each variable are presented in the table below.

Empirical Results and Analysis

Baseline Estimates

The table illustrates the impact of digital finance on the efficiency of green economic growth. The computed coefficient for the digital finance index in Table 2, column (1), is 0.1461, signifying a significantly positive association at the 1% significance level. This indicates that digital finance significantly contributes to the enhancement of green economic growth efficiency.

Columns (2) to (4) of Table 2 display the results of the regression analysis employing the three secondary indicators from the Digital Finance Index as explanatory variables. The computed coefficients for these three variables, namely, breadth of digital financial inclusion coverage, depth of digital financial usage, and digitalization of digital finance, are 0.1427, 0.1033, and 0.0925, respectively. All of these coefficients exhibit statistically significant positive associations. This implies that, first and foremost, reaching a more extensive and diverse customer base with financial products and services contributes to a more effective correction of factor allocation distortions. It also allows for the advantageous utilization of the convenience, high efficiency, and reduced transaction costs offered by digital inclusive financial services, leading to a rational redirection of funds towards green industries. Consequently, transaction costs associated with green financial products can be efficiently reduced, promoting increased efficiency in green economic growth. Second, the ongoing expansion of the depth of digital finance usage provides a variety of financial products and services to meet the demand side's needs, increasing the availability of financing, reducing transaction costs,

Table 2. Benchmark regression.

	(1)	(2)	(3)	(4)
	GEE	GEE	GEE	GEE
Index	0.1461***			
	(0.0428)			
Breadth		0.1427***		
		(0.0413)		
Depth			0.1033**	
			(0.0435)	
Digitization				0.0925***
				(0.0282)
Urban	0.4663***	0.4760***	0.4387***	0.4289***
	(0.1266)	(0.1273)	(0.1263)	(0.1257)
Finance	-0.0638*	-0.0655*	-0.0574	-0.0586*
	(0.0353)	(0.0354)	(0.0352)	(0.0352)
PGDP	-0.1799**	-0.1898**	-0.1086	-0.1293*
	(0.0805)	(0.0821)	(0.0763)	(0.0726)
Fiscal	-0.1946	-0.2000	-0.0022	-0.0986
	(0.4054)	(0.4059)	(0.3997)	(0.3987)
Education	0.0658**	0.0641**	0.0624**	0.0700**
	(0.0270)	(0.0271)	(0.0269)	(0.0273)
Constant	1.8034**	1.9535**	1.2419*	1.4640**
	(0.7467)	(0.7674)	(0.7140)	(0.7074)
N	2050	2050	2050	2050
R^2	0.696	0.697	0.719	0.720

Note: Standard errors are in parentheses; ***, ***, and * indicate significant levels at 1%, 5%, and 10%,

and enhancing resource allocation efficiency. Third, the rapid growth of digital technology effectively addresses challenges related to fragmented credit data and homogenization, as well as "information silos."

Digital finance offers the advantages of cost-effectiveness, heightened efficiency, and extensive accessibility in comparison to traditional finance. On one hand, the widespread availability of digital finance streamlines payments for various transactions, eliminates time and location constraints in the purchasing process, and bolsters society's overall effective demand. Moreover, the heightened efficiency of digital finance has the potential to enhance the efficiency of financial services, thereby contributing to the growth of the city's green economy. On the other hand, digital inclusion plays a role in reducing financing costs and overall business expenses, making enterprises more inclined to establish themselves in regions with well-developed digital inclusion. Lastly, digital inclusion promotes green development by stimulating eco-friendly manufacturing processes, encouraging public involvement in environmental protection, and driving investments in green initiatives.

Concerning control variables, the regression coefficient for population urbanization is notably positive, signifying that population urbanization can enhance green development efficiency through various positive effects, including reduced transaction costs and economies of scale as populations and economic activities concentrate in urban areas. The regression coefficient for financial development implies a significant misalignment in traditional local finance in China, with financial resources flowing into conventional high-pollution and high-emissions industries. The regression coefficient for GDP per capita highlights that the Chinese government has not fully transitioned away from the GDP-centric mindset in economic and social development over the recent period, leading to haphazard economic development that places immense strain on resources and the environment, negatively impacting green development efficiency. The regression coefficient for government fiscal spending is not significant, possibly due to the policy bias towards GDP as it constrains industrial structural upgrades, rendering its influence on regional green economic growth less discernible. In contrast, the positive regression coefficient for human capital level, passing a 5% significance test, suggests that the development of population quality contributes to regional green economy efficiency. As citizens' educational levels increase, their capacity for innovation and environmental awareness will likely bolster green economy efficiency in urban areas.

Endogenous Problem Solving

While this study incorporated control for city-level factors such as economic development and human capital in the baseline regression, other unobservable city economic characteristics may still influence the efficiency of urban green economy development, introducing endogeneity concerns like omitted variable bias. To address this endogeneity issue, this research employs the distance between the sample cities and Hangzhou as the instrumental variable for the digital finance index. Firstly, as a natural geographical variable, the distance between the sample city and Hangzhou remains unrelated to economic and social aspects, and it exerts no impact on the city's green total factor output. Secondly, Hangzhou's level of digital finance development stands as a leading and representative benchmark in both China and globally. Closer proximity to Hangzhou correlates with a higher level of digital finance development for each prefecture-level city, establishing a direct relationship between the distance

Table 3. Endogenous problem processing results.

	(1)	(2)	(3)
	OLS estimation	First phase(Index)	2SLS-IV
IV		-0.0327***	
		(0.0114)	
Index	0.1518***		0.0965***
	(0.0436)		(0.0140)
Cons	0.7030	-2.4791**	4.8386***
	(0.5334)	(0.2928)	(1.4056)
Control variables	Yes	Yes	Yes
N	2055	2047	2047
R^2	0.799		0.359
F Statistic		403.90***	

Note: Standard errors are in parentheses; ***, ***, and * indicate significant levels at 1%, 5%, and 10%

from the sample city to Hangzhou and the level of digital inclusive finance development. As a result, the instrumental variables employed in this study satisfy the correlation and exogeneity criteria.

The results of the initial stage regression analysis, presented in Table 3, support the legitimacy of the distance between the sample cities and Hangzhou as an instrumental variable. The findings from the subsequent stage of regression analysis indicate that, even after thorough adjustment for endogeneity bias, the regression coefficients of the key variables remain significantly positive. Furthermore, there is no substantial alteration in the direction or significance of these coefficients when compared to the baseline regression results. This suggests that the regression results remain robust even after addressing endogeneity within the model.

Additionally, given that the credibility of the instrumental variables influences the validity and consistency of the estimate findings, we conducted the following statistical tests on the instrumental variables employed in the 2SLS approach in this paper: (1) The F-value for the first stage of the instrumental variables was 403.90, significantly surpassing the threshold of 10, thus alleviating concerns about weak instrumental variables; and (2) the P-value of the Sargan statistic exceeded 0.01, signifying that the instrumental variables adhere to the exogeneity principle. Even after adjusting for endogeneity, the results continue to suggest that digital finance can substantially enhance the efficiency of green economic growth.

Regional Heterogeneity Analysis

Considering China's vast geographical extent and substantial disparities in geographical location and resource endowments among the eastern, central, and western regions, the impact of digital banking on urban green economies may differ. Consequently, this study categorizes the 285 cities into eastern, central, and western provinces to examine regional disparities in the effects of digital finance on green economy efficiency.

The impact of digital banking on green economy efficiency exhibits significant variation, as revealed by the table findings. In the eastern region, digital finance substantially enhances urban green economic efficiency, and in the central region, it contributes significantly at the 10% significance level. However, it does not have a significant impact on urban green economic efficiency in the western region. This disparity suggests that digital financial inclusion plays a more prominent role in bolstering green economic efficiency in the eastern region compared to the central and western regions. This discrepancy can largely be attributed to the "substantial initial investment and low marginal cost" of digital finance. In the absence of coverage bottlenecks, the eastern region benefits more due to its well-developed infrastructure, effective regulatory measures, and a large user base. The eastern region's economic infrastructure and key cities attract a considerable influx of talent and technological expertise, and its innovation factors' aggregation capacity exceeds that of the central and western regions and other typical cities. These factors make the influence of digital finance on green economy development in the eastern region more pronounced [31].

Analysis of Moderating Effects

Does the previous benchmark regression imply that increasing the level of urban digital finance will invariably result in enhanced urban green economy efficiency? In reality, the influence of digital finance on the efficiency of green economic growth is not solely determined by the city's level but may also be moderated by other variables, such as the city's degree of technological innovation and industrial structure. The unique circumstances of each city can influence the driving force of digital finance on green economy efficiency. In line with these considerations, this study introduces a cross-multiplication term involving digital finance, city technological innovation, and industrial structure level based on the Equations (1).

Table 4. Analysis of heterogeneity by region.

	(1)	(2)	(3)
	Eastern Region	Central Region	Western Region
Index	0.1904***	0.1852**	0.0306
	(0.0640)	(0.0865)	(0.0401)
Cons	2.1175*	2.2017	0.9976
	(1.2849)	(1.3779)	(0.7123)
Control variables	Yes	Yes	Yes
N	886	586	578
R^2	0.288	0.201	0.310

Note: Standard errors are in parentheses; ***, ***, and * indicate significant levels at 1%, 5%, and 10%

Table 5. Analysis of regulatory effects.

	(1)	(2)
	GEE	GEE
Index	0.3503***	0.1227**
	(0.1124)	(0.0497)
Innovation*Index	0.1501**	
	(0.0755)	
IS*Index		0.4881***
		(0.0597)
Cons	-0.3590	1.9322**
	(1.1888)	(0.7482)
Control variables	Yes	Yes
N	2042	2060
R^2	0.236	0.112

Note: Standard errors are in parentheses; ***, ***, and * indicate significant levels at 1%, 5%, and 10%

The number of patents issued per capita is used to indicate urban technological innovation in order to examine the influence of digital finance on the efficiency of green economy growth through influencing technological innovation. The projected cross multiplier relationship between digital financial inclusion and urban technological innovation is highly positive, showing that a favorable urban innovation environment reinforces the efficiency of digital finance for green economic growth. The urban innovation environment is critical for financial technology and financial service model innovation. Fintech innovation is one of them, and it is the engine that drives the growth of digital finance, while a robust innovation environment is a vital basis for fintech R&D. Fintech R&D can be carried out more orderly in an innovation ecosystem, and technological achievements can be applied to digital inclusive finance services to further expand its advantages of convenience and inclusiveness, thus contributing to the effectiveness of enhancing the development of the green economy.

To evaluate how digital finance affects the efficiency of green economy growth by modifying the industrial structure, we employ the estimated result obtained by introducing the cross-product term of digital finance and industrial structure to assess the significance of digital finance. The computed coefficient of the cross-product term is strongly positive, indicating that the driving impact of digital inclusive finance on the efficiency of urban green economy growth further enhances as the industrial structure undergoes continuous optimization and upgrading.

Expanded Analysis

To further investigate the environmental implications of digital banking, we conduct a separate analysis in our expanded research to assess the effects of digital finance on environmental pollution and carbon emissions.

The computed coefficient of digital finance in model (2) of Table 6 is -0.3099 and is statistically significant

Table 6. Robustness test.

	(1)	(2)	(3)	(4)
	ln_polution	ln_polution	ln_co2	ln_co2
Index	-0.7513***	-0.3099***	-0.1100***	-0.1691***
	(0.0213)	(0.0402)	(0.0334)	(0.0339)
PGDP		-0.2074*		0.4865***
		(0.1186)		(0.0712)
IS		-0.5088***		0.3265***
		(0.0448)		(0.0465)
Fiscal		-1.6137***		-0.0060
		(0.4895)		(0.3676)
Finance		-0.0048		0.1129***
		(0.0273)		(0.0314)
Constant	13.4161***	16.4079***	-4.0273***	-4.0654***
	(0.1180)	(0.6529)	(0.6075)	(0.6712)
N	2538	2464	2406	2127
R^2	0.361	0.436	0.027	0.048

Note: Standard errors are in parentheses; ***, ***, and * indicate significant levels at 1%, 5%, and 10%

at the 5% level. This means that for every 1% growth in digital finance, there is a corresponding 0.3099% reduction in the emission intensity of urban pollution. This implies that digital finance contributes to the reduction of greenhouse gas emissions. Digital finance, enabled by technologies like the Internet, big data, and cloud computing, has the potential to effectively identify the market prospects of environmental protection projects and green products. It can also alleviate the resource allocation mismatch caused by information asymmetry, support the development of environmental protection projects and green industries, and consequently reduce pollution emissions. The coefficient reflecting the impact of digital finance on carbon emissions in models (3) and (4) is significantly negative, indicating that the robust development of inclusive finance assists cities in lowering emissions and promoting a green and low-carbon transformation, confirming hypothesis 1. Digital inclusive finance eliminates the time and space constraints associated with financial services, streamlines business processes, enhances the availability and convenience of financial services, and improves enterprises' financing requirements. This stimulation of innovation and entrepreneurship contributes to green transformation. The amalgamation of inclusive finance facilitated by digital technology with green finance allows for the expansion of green financing, which aids in reducing carbon emissions.

Conclusion

Digital finance plays a crucial role in China's strategy for green and low-carbon economic development. It distinguishes itself from traditional credit industries in terms of coverage, usage depth, and degree of digitization, resulting in substantial disparities in the processes and outcomes related to green economy expansion. This empirical research investigates the impact of digital finance on the efficiency of green economic development in China's prefecture-level cities and extends its assessment to include the effects of digital finance on environmental pollution and carbon emissions in China from 2011 to 2019. The empirical results indicate that digital finance can significantly enhance the efficiency of urban green economy development and that it does so across three dimensions: breadth of coverage, depth of usage, and degree of digitization. Furthermore, the heterogeneity analysis reveals that the impact of digital finance on green economic efficiency varies by location, with the promotion of digital inclusive finance exerting a more pronounced influence on green economic efficiency in eastern regions compared to central and western regions. Additionally, the driving effect of digital finance on the efficiency of green economic growth depends not only on the city's level but also on other factors, such as the city's level of technological innovation and industrial structure. Lastly, the findings from the extended study suggest that digital finance may lead to a reduction in regional pollutant emissions and carbon emissions, thereby enhancing the quality of development in China's green and low-carbon economy.

Policy Implication

We must wholeheartedly support the advancement of a digital China and establish a fresh catalyst for green growth. The central Chinese government should coordinate efforts, refine the high-level blueprint for digital economy growth, delineate the future direction of China's digital economy, and formulate a comprehensive strategy for the medium- and long-term development of China's digital economy. To drive sustainable development, it is imperative to harness the positive impact of inclusive digital finance on technological progress. Governments at all administrative levels should optimize the advantages of digital finance by capitalizing on its accessibility, advocating for enhanced informatization, digitization, and intelligence within the financial sector, directing internet-based funding toward SMEs through improved financial efficiency, augmenting R&D investments, and nurturing further technological innovation.

Employing a blend of financial and industrial policies, incentives, and regulatory measures, we will steer social capital toward sectors with "low energy consumption, low pollution, and high efficiency" to expedite the green makeover of green and low-carbon industries, fostering their development. Furthermore, we will persistently bolster the institutional framework to facilitate the convergence of digital technology and financial services, including digital inclusive finance, in order to establish an all-encompassing service blueprint for green economic growth.

Considering disparities in the progress of new-generation information technologies like big data, cloud computing, and artificial intelligence across different cities, tailored development policies should be crafted, taking into consideration the region's resource endowment, industrial makeup, and level of openness. In regions with well-developed economies, the advancement of digital inclusive finance should prioritize innovation in models, reinforce the benefits of clustering, and enhance the "quality" of digital inclusive finance. Conversely, in economically less advanced regions, the focus should be on initially broadening the reach of digital inclusive finance, while elevating the accessibility of financial services through heightened investment in digital infrastructure and reinforcing the benefits of clustering. To establish the "quantity" of digital inclusive finance in economically disadvantaged regions, the primary steps involve extending the coverage of digital inclusive finance and enhancing the universality of financial services via increased investments in digital infrastructure and bolstering the penetration of digital finance.

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Author Contribution Statement

Gongliang Wu: Conceived and designed the experiments; Wrote the paper. Yueling Cai: analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

Data Availability Statement

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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