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The Impact of Digital Financial Inclusion on Regional Green Innovation Research

-- Empirical Evidence from 281 Prefecture-level Cities in China

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Abstract: Relying on green technological innovation and developing green technology is an important support for the green transformation of society. This paper empirically analyzes the impact and mechanism of digital finance on green innovation by comprehensively applying fixed effect model, multiple linear regression and mediation effect model. The results show that digital inclusive finance can significantly incentivize green innovation, and the conclusions remain robust after multiple robustness tests. The mediation effect analysis shows that digital inclusive finance can enhance entrepreneurial activity, promote industrial structure optimization and alleviate financing constraints, and then promote the development of green innovation. Heterogeneity analysis shows that heterogeneous factors such as the size of the non-state economy, environmental regulations, and distance from Hangzhou make significant differences in the impact of digital inclusive finance on regional green innovation. Therefore, the application of digital inclusive finance in the field of green innovation should be strengthened, digital inclusive finance supporting equipment and systems should be vigorously constructed and improved, digital inclusive finance development strategies should be formulated according to local conditions, and other factors should be coordinated to play a role in conjunction with digital inclusive finance in order to guide green transformation.

Keywords: Digital inclusive finance; green innovation; entrepreneurial activity; financing constraints; industrial structure upgrading.

1. Introduction

With the continuous development of the times, innovation has become an intrinsic requirement for the sustained and stable development of China's economy and a decisive factor in the competition for comprehensive national power, however, excessive reliance on the development of science and technology has also brought about tremendous pressure on environmental pollution, ecological damage, and harm to human health. According to the Bulletin of China's Ecological and Environmental Conditions in 2020, only 58.9% of China's cities in 2020 have met the environmental quality standards, while the environmental performance indicators rank 120th in the world. With the deterioration of environmental problems, the country's attention to green innovation has increased, and the level of green innovation in various regions has gradually been developed, but the proportion of green innovation is still not high.2022, the National Development and Reform Commission and the Ministry of Science and Technology jointly issued the Implementation Program, which proposes to build a pattern of green technological innovation, and promote green technological innovation.

With the in-depth application of digital technology in the financial field, digital inclusive finance has been booming since 2011. Digital inclusive finance is a product of the innovation and expansion of digital technology on traditional finance, with the advantages of fast speed, wide coverage, low cost and low threshold, significantly reducing transaction costs, broadening the scope of financial services, enriching the form of inclusive financial products and services, and the ability to use digital technology to cultivate the ability of big data risk prevention and control and reduce the external financing constraints of green innovation activities, and at the same time, through the broadening of financing channels, to absorbing social idle funds, providing abundant financial support for regional green innovation activities (Ren Senchun and Zhao Lei, 2022), which deeply fits the needs of regional green innovation. So can digital inclusive finance support the development of regional green innovation? By reviewing and organizing the literature, it is found that through combing the literature, the current theory on the impact of digital inclusive finance on green innovation is gradually enriched and perfected, but the relevant research based on the regional level is still in its infancy, and most of the existing research analyzes the financing constraints, industrial structure, and other single aspects, and the corresponding role of the mechanism and the intermediary effect need to be further explored and improved, and the research perspective and content need to be supplemented and explored. The research perspectives and contents need to be supplemented and explored, and at the meso level, the influence mechanism of digital inclusive finance in realizing green innovation and promoting green transformation can be explored more from the regional dimension. Therefore, by processing and analyzing the relevant data of Chinese cities, this paper thoroughly explores the influence effect of digital inclusive finance on regional green innovation, and at the same time, based on panel data, constructs a theoretical analysis framework from the perspectives of innovation activity, industrial structure optimization and financing constraints, and comprehensively applies the methods of multiple regression model, heterogeneity test and robustness test to identify the influence mechanism of digital inclusive finance on regional green innovation in a more systematic manner, so

as to identify the influence mechanism of digital inclusive finance on green innovation and promote the green transformation. regional green innovation, so as to draw more in-depth and detailed research conclusions, enrich the theoretical research on digital inclusive finance and regional green innovation in China, and provide reference for promoting regional green innovation.

2. Theoretical Analysis and Hypothesis Derivation

With the introduction of the concept of "digital inclusive finance" and the maturation of the evaluation system, scholars have begun to study the intrinsic connection between it and enterprise or regional green innovation. Liang Bang and Zhang (2019) point out that digital inclusive finance can significantly and positively promote enterprise technological innovation. Tang Song et al. (2020) and Wan Jiayu et al. (2020) scholars, on the other hand, all agree that digital inclusive finance can promote corporate innovation by alleviating corporate financing constraints. Zhuang Qinqin et al. (2020) point out that financial instruments are indispensable to support long-term large-scale capital investment in corporate green technology innovation. After that, scholars such as Wang Zhixin et al. (2022) based on corporate panel data show that the development of digital finance has an important role in promoting green innovation of companies. The study of Zhai Huayun and Lewis (2021) also shows that digital inclusive finance can alleviate corporate financing constraints and thus promote green innovation, and a few scholars have also explored the mechanism of the impact of digital inclusive finance on the efficiency of green innovation, such as Yin Feixiao's (2020) related study shows that digital inclusive finance has a significant impact on the efficiency of green innovation in the local and neighboring regions, and it can improve the local efficiency of green innovation, but has a siphoning effect on the green innovation efficiency of neighboring regions, and there is heterogeneity among cities of different sizes. And because the R&D investment of enterprises as a kind of operating expenditure is difficult to reveal the actual innovation results of enterprises exactly (Xu Jia and Cui Jingbo, 2017), scholars gradually thus turn to the number of green patents applied for and obtained by enterprises to evaluate the degree of green innovation of enterprises (Popp, 2006; Calel and Dechezleprêtre, 2016).

2.1. Analysis of the impact mechanisms of digital financial inclusion on regional green innovation

As an organic combination of digital technology and financial inclusion, digital financial inclusion has brought significant empowerment effects, and has been regarded as an important focus of financial supply-side reform and a driving force for economic growth in many regions. According to Wang Min and other scholars (2023), through its basic characteristics such as "universality" and multiple channels, digital financial inclusion plays a significant role in stimulating enterprises to carry out innovative activities. As a new financial service model, digital inclusive finance can break the limitations of traditional finance by virtue of intelligent technology, provide more convenient financial services for both the supply and demand sides of funds, and also alleviate the problem of information asymmetry to a certain extent, injecting vitality into the green innovation activities in the region.

With the level of digitization pushed up another dimension, digital inclusive finance has the ability to re-optimize the traditional financial system to a certain extent, which can improve the problems in regional innovation activities and the mismatch between scientific and technological resources and financial resources, narrowing the gap for regional innovation and thus providing the necessary conditions for the development of innovation activities (Xin Zhang and Xiaohong Lan, 2022). Digital inclusive finance has an important role in the field of green innovation, on the one hand, it can effectively reduce the threshold and transaction costs of traditional financial services, guide the flow of funds from high-pollution industries to low-pollution and green sectors through the cross-innovation of financial products, and promote the effective allocation of resources (Lan Zirui and Zhang Shuhua, 2023); on the other hand, digital inclusive finance can utilize its universality to serve small and micro-enterprises, help them to On the other hand, digital inclusive finance can utilize its universality to serve micro and small enterprises, help them carry out more flexible financial activities, reduce the financing threshold of enterprises, and help their green innovation activities, and it can reduce the information gap and information acquisition cost by taking advantage of data processing and analysis, thus reducing the financing cost of green innovation subjects and helping regional green innovation. Based on the above analysis, this paper puts forward hypothesis 1.

Hypothesis 1: Digital financial inclusion can significantly promote regional green innovation.

As an emerging product in the digital era, the development of digital inclusive finance is affected and constrained by the level of regional economy (Li Ping and Richard Li, 2023)[10] . From the green innovation index across the country, it seems that the level of digital economic development in China's regions has been developing, but the development gap is large. Among them, the development of digital inclusive finance has been saturated in the eastern region, but it has not been fully developed in the central and western regions (Li Zonghan and Zheng Jianghuai, 2023), i.e., in the more economically developed regions, the degree of development of digital inclusive finance will also be higher. And due to the impact of factors such as the level of urban economy, geographic location conditions, government innovation preferences and institutional environment optimization (Zheng Wei and Jiang Tangyang, 2023), there are obvious differences in the level of green innovation presented in each region in China (Sun Qunying et al., 2019). Summarizing the above, it can be obtained that due to the existence of imbalance in the development between regions, the impact of digital inclusive finance on green innovation plays a role of different degrees and effects in space. Based on this, this paper proposes hypothesis 2.

Hypothesis 2: There is significant regional heterogeneity characterizing the impact of digital financial inclusion on green innovation.

2.2. Theoretical assumptions on intermediation mechanisms

2.2.1. Entrepreneurial activity

Entrepreneurial activity refers to the frequency of entrepreneurial activities in a particular region, reflecting the quality, capacity and performance of regional entrepreneurial activities (Shouwei Li, 2021). At the macro level, the digital

economy can stimulate regional entrepreneurial activity and promote urban green innovation (Wei Lin and Ma Mengru, 2022). And digital inclusive finance broadens the financing channels of local entrepreneurs and reduces the cost of entrepreneurship by alleviating the asymmetry of information, while the development of the entrepreneurial environment is to a certain extent conducive to stimulating the innovative main body to put more resources and energy into green innovation activities, and continues to stimulate green entrepreneurial enthusiasm in the whole society, thus driving regional green innovation. Therefore, this paper proposes hypothesis 3.

Hypothesis 3: Digital financial inclusion positively impacts regional green innovation by increasing entrepreneurial activity.

2.2.2. Financing constraints

Compared with other investment projects, the output of innovation has a high degree of uncertainty, and the willingness of banks to lend is low, which leads to the technological innovation of SMEs will be subject to great external financing constraints (Xiang Dong et al., 2023). Compared with traditional finance, digital inclusive finance can play a better role in resource support, profoundly change the financing mode of enterprises, reduce the cost of financing, and solve the problem of "difficult and expensive financing" (Zheng Hua and Xiao Hua, 2023). Some studies have shown that a developed financial system can provide enterprises with a high-quality external financing environment, which can effectively alleviate their financing constraints (Rajan & Zingales, 1998; Claessens & Laeven, 2003). Digital inclusive finance can meet the financing needs of long-tail customers, relying on the integration and innovation of the underlying technology in the financial field, and help solve the enterprise financing difficulties (Huang Rui et al., 2021). The implementation of environmental regulation policy puts forward higher requirements on the production of enterprises, forcing enterprises to increase investment in green technology upgrading and innovation, digital inclusive finance breaks the exogenous financing constraints, and to a certain extent, it can alleviate the financing constraints predicament of green industry and high-tech industry's green innovation main body (Han Yaching et al., 2023), and to a certain extent, it can provide financial support for the region's green innovation. Therefore, hypothesis 4 can be derived.

Hypothesis 4: Digital inclusive finance promotes regional green innovation by alleviating financing constraints.

2.2.3. Optimization of industrial structure

With the continuous integration and development of digital inclusive finance, a new round of industrial structure is also transformed under its drive. Based on the advantages of reducing the financing threshold, improving the financing efficiency and alleviating the asymmetry of market information, digital inclusive finance empowers the transformation of the industrial structure and can effectively promote the upgrading of the industrial structure (Liu Xin and Han Qing, 2023). With the continuous adjustment and improvement of the regional industrial structure, high-pollution and high-energy-consuming industries are constantly eliminated and optimized, thus reducing energy loss and environmental pollution (Binbin Yu, 2017), which in turn improves the efficiency of green innovation and promotes regional green innovation. Based on this, hypothesis 5 is obtained.

Hypothesis 5: Digital inclusive finance can dynamically restructure industries and thus promote regional green innovation.

3. Research Design

3.1. Data sources

This paper takes 281 prefecture-level counties and cities in China as the research object, and constructs a data panel around the digital financial inclusion and regional green innovation index from 2011 to 2019. In response to the problem of missing data generated by administrative division adjustment, this paper makes up for it by linear interpolation and eliminates invalid samples. The digital financial inclusion index and regional green innovation index are taken from the Digital Finance Research Center of Peking University and the China Research Data Service Platform (CNRDS), respectively; enterprise-related information is provided by the CSMAR and WIND platforms; and the rest of the prefecture and county-level data come from national as well as provincial statistical yearbooks.

3.2. Selection of variables

Given the existence of multiple sub-dimensional variables for some of the variables, entropy measures were used for individual variables. In statistics, entropy implies the concept of disordered scatter, which is able to measure the degree of dispersion of the indicator and introduce the degree of disorder and randomness of the event. The smaller the entropy value of the indicator, the greater the influence (weight) on the event. The formula for the entropy method to find the weight is as follows:

$$\omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

3.2.1. Explained variable - regional green innovation

Academics currently measure regional green innovation mainly from the perspective of regional innovation inputs and benefit outputs. However, there are multiple uncertainty risk factors from innovation inputs to benefit outputs, and the use of input indicators to measure innovation outcomes is prone to bias (Liu Guangzhou, 2022). Therefore, this paper measures green innovation from the perspective of innovation output and benefit by the number of regional green patents granted.

3.2.2. Core explanatory variable - digital financial inclusion

Guo Feng et al. (2021) argued that the degree of development of digital finance in prefecture-level cities can be reflected by the digital inclusive finance index. Zhong Tingyong et al. (2022), on the other hand, a number of scholars consistently classify the sub-dimensions of digital financial inclusion into breadth of coverage, depth of use and degree of digitization. Therefore, this paper takes the digital inclusive finance index as the core explanatory variable and includes the three sub-dimensions in the benchmark regression to compare the heterogeneity of different dimensions.

3.2.3. Control variable

In the study of scholars such as Yanlong Li (2022), government research expenditure, talent reserve, degree of economic development, intensity of foreign direct investment and level of infrastructure may affect regional green innovation. Therefore, this paper refers to previous literature

and takes the proportion of government science and technology expenditure to fiscal expenditure, the balance of students enrolled in general higher education schools per 10,000 people, GDP per capita, the ratio of the amount of foreign direct investment actually utilized by the region to GDP, and the indicator of urban road area per capita as the control variables, respectively.

3.2.4. Mediating variables - industrial structure optimization, entrepreneurial activity, financing constraints

The optimization of industrial structure refers to the measurement method of Gan Chunhui et al. (2020), which is divided into two sub-dimensions: the advanced industrial structure and the rationalization of industrial structure. Among them, the industrial structure advanced focuses on the high-quality development of the industry, while the industrial structure rationalization focuses on the reasonable degree of coordination of industrial resource allocation. The entrepreneurial activity is divided into three dimensions according to the number of new enterprises, the number of inward investments and the number of vcpe investments and measured by entropy weight method according to Bai Junhong et al. (2022). The weight coefficients of the sub-dimensions of entrepreneurial activity are shown in Table 1:

Table 1. Entrepreneurial Activity Sub-Dimensions

term	The information entropy value e	Information utility value d	Weighting factor w
Number of new business entries	0.9976	0.0023	28.55%
Number of inward investments	0.9976	0.0023	27.80%
Number of vcpe investments	0.9964	0.0036	43.65%

Among the three sub-dimensions of entrepreneurial activity, the weight of the number of new firm entries is 28.55%, the weight of the number of inward investments is 27.80% and the weight of the number of vcpe investments is 43.65%. This indicates that the amount of vcpe fundraising has the greatest impact on entrepreneurial activity, followed by the number of new firm entries, and the weight coefficient of the number of inward investment pens and the number of new firms are not similar, but have the least impact. Thus the following formula is derived:

$$EA = 0.2855 \cdot Entry + 0.2780 \cdot Number + 0.4365 \cdot Amount$$

The WW, KZ and SA indices are the most widely used methods for measuring financing constraints in existing studies. Among them, WW index and KZ index usually include endogenous financial variables, and SA index has a limited scope of application. Therefore, the financing constraint index (FC) in this paper is calculated by referring to the measurement method of Gu Leilei et al. The larger the value of FC, the more serious the impact of financing constraints on the enterprise.

Table 2. Variable selection and measurement

Variable type	variable name	Sub-dimensional variables	bibliography
Core explanatory variables	Digital Inclusive Finance	breadth of coverage	Guo Feng, 2021
		Depth of use	
		Degree of digitization	
explanatory variable	Regional Green Innovation	Number of green patents granted	Zhai, Huayun and Lewis, 2021
intermediary variable	Optimization of industrial structure	Advanced industrial structure	Chunhui Gan, 2011
		Rationalization of industrial structure	
	Entrepreneurial activity	Number of new business entries	Liu Wei and Dai Bingqing, 2022[17]
		Number of inward investments	
		Number of vcpe investments	
	Financing constraints	Operating cash flow/financial expenditure	Gu Lei Lei, 2020
control variable	Intensity of government research expenditure	Government expenditure on science and technology/fiscal expenditure	Liu Guangzhou, 2022 / Li Yanlong, 2022
control variable	talent pool	Number of students enrolled in general higher education / 10,000	Liu Guangzhou, 2022 / Li Yanlong, 2022
	Level of economic development	GDP per capita	
	Intensity of foreign direct investment	FDI/GDP	
	Level of infrastructure	Road area per capita	

3.3. Descriptive statistics

The analysis successively passes through data patching, data matching, and screening of valid data samples, resulting in empirical data containing 281 cities from 2011-2019. The descriptive statistics of the main variables are shown in Table 3.

Table 3. Variable Selection and Measurement

variable name	Number of variables	minimum value	maximum values	average value	(statistics) standard deviation
Digital Inclusive Finance	2528	2.83	5.77	4.99	0.51
Regional Green Innovations	2533	0.00	7.63	2.73	1.63
Advanced industrial structure	2533	0.11	3.81	0.74	0.35
Rationalization of industrial structure	2533	-1.22	7.58	1.59	0.98
Entrepreneurial activity	2563	0.34	8.28	2.84	1.68
Financing constraints	2520	-10.21	0.87	0.04	0.12
breadth of coverage	2528	0.62	5.73	4.91	0.57
Depth of use	2528	1.45	5.80	4.97	0.51
Degree of digitization	2528	0.99	6.36	5.16	0.62
Number of new business entries	2563	-1.07	4.60	3.61	1.03
Number of inward investments	2563	-1.05	4.60	3.53	0.51
Number of vcpe investments	2563	-6.80	4.61	3.58	1.41
Intensity of government research expenditure	2533	0.00	0.20	0.01	0.01
talent pool	2533	-3.98	4.68	1.29	1.32
Level of economic development	2533	8.77	13.05	10.67	0.57
Intensity of foreign direct investment	2533	-0.00	1.31	0.11	0.15
Level of infrastructure	2533	4.70	14.36	8.52	0.97
Note: The data in the table are logarithmic.					

3.4. Modeling

According to the research hypotheses of this paper, the panel model is constructed as follows based on the study of Zhang Jiefei et al:

$$RGI = \alpha + \beta_1 DF_{it} + \beta_2 control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where i denotes the prefecture, and t refers to time; the explanatory variable RGI_{it} refers to the degree of green innovation in i prefecture at t ; the core explanatory variable DF_{it} refers to the level of digital inclusive finance development in i prefecture at t ; $Control_{it}$ refers to the relevant control variables that may affect regional green innovation; μ_i denotes the individual effect that does not vary over time, λ_t refers to the time fixed effect; ε_{it} is a randomized perturbation term; α is a constant term; β_1 and β_2 are the parameters to be estimated.

In order to further test whether the optimization of industrial structure, entrepreneurial activity, and corporate financing constraints have a transmission role in the process of the impact of digital inclusive finance on regional green innovation, this paper refers to the study of Liu Guangzhou et al. (2022) and constructs the mediation effect model as follows:

$$M_{it} = b_0 + b_1 DF_{it} + b_2 control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$RGI_{it} = b_0 + b_1 DF_{it} + b_2 control_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

In equation (2), M refers to the mediating variables, including the two sub-dimension variables of industrial structure optimization and entrepreneurial activity, and the rest of the variables are set the same as in equation (1). In Eq. (1), β_1 refers to the total effect of digital inclusive finance on regional green innovation, c_1 refers to the direct effect of digital inclusive finance on regional green innovation, and $b_1 \cdot b_2$ is the mediating effect of digital inclusive finance on regional green innovation through mediating variables.

4. Empirical Analysis

4.1. Analysis of baseline regression results

In this paper, a two-way (individual and time) fixed effects model is used for the benchmark regression, and the results are shown in the table 4:

Table 4. Variable Selection and Measurement

variant	Regional Green Innovation				
	(1)	(2)	(3)	(4)	(5)
Digital Inclusive Finance	0.728***	0.658***	-	-	-
	(24.37)	(8.72)	-	-	-
Breadth of digital financial inclusion coverage	-	-	0.542***	-	-
	-	-	(6.79)	-	-
Depth of use of digital financial inclusion	-	-	-	0.477***	-
	-	-	-	(6.23)	-
Digital Inclusion Level of financial digitization	-	-	-	-	0.336***
	-	-	-	-	(3.89)
Level of regional economic development	-	0.289***	0.327***	0.360***	0.349***
	-	(7.23)	(8.19)	(8.72)	(8.46)
overseas foreign direct investment (OFDI)	-	-0.312**	-0.252**	-0.198**	-0.288**
	-	(-1.72)	(-1.52)	(-1.12)	(-1.46)
Level of government expenditure on science and technology	-	0.239**	0.357***	0.321***	0.306***
	-	(2.43)	(3.69)	(3.25)	(3.08)
talent pool	-	-0.002	-0.005	-0.002	-0.006
	-	(-0.02)	(-0.43)	(-0.05)	(-0.36)
Level of infrastruc -ture	-	-0.064**	-0.062**	-0.056**	-0.064**
	-	(-1.22)	(-1.19)	(-0.77)	(-0.62)
constant term (math.)	0.486***	-0.862	-1.018*	-0.131*	-1.142**
	(5.22)	(-2.19)	(-3.77)	(-0.62)	(-2.13)
Time & City	containment	containment	containment	containment	containment
R^2	0.656	0.663	0.659	0.661	0.663
item count (of a consignment etc)	2513	2513	2513	2513	2513
Note: * represents significant at 1%, ** represents significant at 5%, *** represents significant at 1%, t-values from robust standard errors in parentheses, below.					

According to Table 4, digital financial inclusion has a significant positive impact on regional green innovation, and Hypothesis 1 is verified. In addition the increase in the breadth of coverage, depth of use and digitization of the sub-dimensions can significantly contribute to the development of regional green innovation capacity, and hypothesis 1 is valid.

In terms of control variables, both the level of government science and technology expenditure and the level of regional economic development can significantly promote the development of regional green innovation; while foreign direct investment inhibits the development of regional green innovation, presumably due to the fact that local governments reduce the quality of foreign direct investment in order to attract foreign investment, which is not conducive to the improvement of regional green innovation in the long run. The positive effect of talent pool and infrastructure level among the control variables on regional green innovation efficiency is not significant, which may be due to the existence of hiddenness or lag.

4.2. Robustness tests

4.2.1. Substitution of explanatory variables

Replacing the number of green patent applications with the explanatory variables, the results are shown in Table 5. The core explanatory variables have a significant positive impact on regional green innovation; the results of other control variables have not changed significantly, proving that the empirical analysis results of the benchmark regression are robust.

4.2.2. Core explanatory variables are taken one period lagged

Considering the possible existence of lagged effects and referring to Zhai Huayun et al. (2022), this paper regresses the lagged one-period of digital financial inclusion, and the results are as follows Table 5 shown. The regression results of the main explanatory variables and control variables do not change significantly, and the results of hypothesis 1 are robust.

4.2.3. Excluding some city samples

Due to the unbalanced development of China's regions, the differences in the economic development and infrastructure level of some cities are more obvious, therefore, this paper excludes the samples of municipalities, provincial capitals and ethnic minority areas from the re-examination, and the results are as follows Table 5. The results are shown in Table 5. The estimated coefficient values of the core explanatory variables and control variables have not changed significantly, and the results of hypothesis 1 are robust.

4.2.4. Variable indentation

In order to avoid the influence of outliers on the regression

results, this paper regresses the main explanatory variables again after shrinking the upper and lower 1%. The results are summarized by Table 5 it can be seen that the results of hypothesis 1 remain robust.

Table 5. Robustness test results

variant	(1) Substitution of explanatory variables	(2) Lagged explanatory variables	(3) Excluding some city samples	(4) variable indentation
Digital Inclusive Finance	0.642***	0.688***	0.592***	0.518***
	(9.42)	(12.63)	(7.64)	(7.21)
constant term (math.)	-2.477**	-1.142*	-1.932**	-4.019*
	(-6.27)	(-3.89)	(-5.83)	(-7.92)
control variable	containment	containment	containment	containment
Time & City	containment	containment	containment	containment
R^2	0.712	0.709	0.788	0.736
item count (of a consignment etc)	2513	2513	2333	2358

4.3. Robustness tests

4.3.1. Regional heterogeneity

Considering the basic national conditions of China's vast region and unbalanced regional development, the regions have very different levels of economic development and infrastructure, and the degree of development of digital inclusive finance also varies. Therefore, this paper divides all regional samples into three groups: east, central and west, in order to explore whether there is regional heterogeneity in the impact of digital inclusive finance on regional green innovation, and the regression results are as follows Table 6 shows.

According to the regression results, digital inclusive finance has a significant positive impact in the eastern, central and western regions, indicating that digital inclusive finance has a facilitating effect on green innovation in different regions and the degree of facilitation is different, there are obvious regional heterogeneity characteristics, hypothesis 2 is established.

Meanwhile, the estimated coefficients of digital financial inclusion for the east, center and west are 0.658, 0.492 and 0.877 respectively, which shows that digital financial inclusion has the most significant impact on green innovation in the west, followed by the east, and the center is the smallest. The possible reason is that the green innovation capacity of the eastern region enters a bottleneck, so the impact of digital inclusive finance on regional green innovation is weaker than that of the west. In the central region, digital inclusive finance has a weaker impact on regional green innovation capacity enhancement due to the lack of digital talents and insufficient government support.

4.3.2. Environmental regulatory heterogeneity

Under appropriate environmental regulation, digital inclusive finance can realize financing innovation through green attributes, meet the financing needs of long-tail customers, and drive the green transformation of high-pollution and high-emission industries as well as credit industries. Therefore, this paper argues that digital inclusive finance has different impacts on green innovation under different environmental regulation intensities. Referring to the established studies, environmental regulation is measured by the inverse of the ratio of the sum of three indicators - industrial wastewater emissions, industrial sulfur dioxide emissions and industrial smoke (dust) emissions - to GDP, and grouped by the mean value. It can be seen from the results in Table 6. Digital inclusive finance has a more significant incentive effect on green innovation in regions with greater environmental regulation intensity, indicating that digital finance can better promote green innovation under the synergy of environmental regulation.

4.3.3. Heterogeneity of distance from Hangzhou

According to Yi Xingjian et al. (2023), there is a close relationship between the development of digital inclusive finance and the city of Hangzhou. As a pioneer in the development of digital finance, Hangzhou has actively promoted the popularization of digital inclusive financial services through technological innovation and policy support. At the same time, its successful incubation of numerous Internet financial platforms has raised financial services to a wider, more convenient and more flexible height through digital technological means, which is not only conducive to the upgrading and optimization of the local industrial structure, but also promotes the development of the regional green economy and improves regional green innovation.

Therefore, this paper argues that the impact of digital inclusive finance on regional green innovation varies in significance depending on the distance of the region from Hangzhou. This paper groups regions by the mean value of their distance from Hangzhou, and the estimation results are as follows Table 6 shows. It can be seen that digital inclusive finance has a stronger promotion effect on regions closer to Hangzhou. The upgrading of Internet services and the improvement and deepening of digital inclusive finance can play a radiation-driven role in promoting the development of regional green innovation.

4.4. Analysis of the mechanism of the mediating effect

Based on existing research, digital inclusive finance may further promote regional green innovation by relaxing financing constraints, strengthening entrepreneurial activity and optimizing and upgrading industrial structure through three channels.

Table 6. Robustness test results

variant	environmental regulation		Distance from Hangzhou	
	(6)	(7)	(8)	(9)
	your (honorific)	lower (one's head)	proximal	distance oneself from (classical)
Digital Inclusive Finance	0.721***	0.534***	0.648***	0.578***
	(9.77)	(6.21)	(9.92)	(7.28)
Level of regional economic development	0.198***	0.012	0.312***	-0.121
	(5.96)	(0.32)	(12.54)	(-0.43)
overseas foreign direct investment (OFDI)	-0.121**	0.012	-0.179**	-0.320**
	(-1.28)	(0.04)	(-1.72)	(-1.81)
Level of government expenditure on science and technology	0.212***	0.182*	0.288***	0.443***
	(3.37)	(1.21)	(4.53)	(10.79)
talent pool	-0.001	-0.004	-0.007	-0.011
	(-0.07)	(-0.01)	(-0.11)	(-0.12)
Level of infrastructure	-0.069**	-0.008	-0.271**	-0.213**
	(-1.07)	(-0.08)	(-0.29)	(-1.30)
constant term (math.)	0.886***	-0.004	0.562***	0.213**
	(3.71)	(-0.06)	(2.98)	(1.32)
Time & City	contain	contain	contain	contain
R^2	0.703	0.682	0.671	0.654
item count (of a consignment etc)	1210	1303	1485	1028

4.4.1. Stimulating regional entrepreneurial activity

As can be seen from Table 7, the regression coefficient of digital inclusive finance on regional entrepreneurial activity is 0.324 and is significant at 1% level. Therefore, digital inclusive finance can stimulate regional entrepreneurial activity by reducing the difficulty of regional entrepreneurial financing and stimulating regional entrepreneurial enthusiasm and willingness to take responsibility. The results of the simultaneous regression of digital financial inclusion and entrepreneurial activity and regional green innovation are still significant but the regression coefficient decreases, which shows that entrepreneurial activity plays a mediating role between digital financial inclusion and regional green innovation, and digital financial inclusion can stimulate entrepreneurial activity, and Hypothesis 3 is established.

4.4.2. Alleviating regional financing constraints

The regression coefficient of digital inclusive finance on financing constraints is 0.782 and significant at the 1% level, indicating that digital inclusive finance can effectively improve regional credit allocation and thus alleviate financing constraints. Table 7 shows that the results of the simultaneous regression of digital inclusive finance and credit allocation are significant, and their regression coefficients are 0.471 and 0.239, respectively, indicating that digital inclusive finance can enhance the regional green innovation capacity by alleviating the problem of financing constraints. Hypothesis 4 is verified.

Table 7. Results of the intermediary mechanism test1

variant	return to baseline	Entrepreneurial activity		return to baseline	Financing constraints	
	(1)	(2)	(3)	(4)	(5)	(6)
	Regional Green Innovation	Entrepreneurial activity	Regional Green Innovation	Regional Green Innovation	Financing constraints	Regional Green Innovation
Core explanatory variables	0.613***	0.324***	0.501***	0.658***	0.782***	0.471***
	(7.28)	(16.22)	(6.69)	(8.72)	(25.63)	(6.79)
intermediary variable	-	-	0.346***	-	-	0.239***
	-	-	(4.21)	-	-	(4.47)
constant term	-1.872	-2.567***	-0.492	-0.862	-4.321***	-0.992
	(-1.79)	(-1.88)	(-0.67)	(-2.19)	(-10.91)	(-1.03)
control variable	contain	contain	contain	contain	contain	contain
Time & City	contain	contain	contain	contain	contain	contain
R^2	0.672	0.761	0.682	0.656	0.702	0.643
aggregate effect	0.613			0.658		
intermediary effect	0.112			0.187		
direct effect	0.501			0.471		
item count	2238	2238	2238	2513	2513	2513

4.4.3. Optimization and upgrading of industrial structure

Table 8 shows the mediation effect test results of digital inclusive finance on the benchmark regression of regional green innovation and the two sub-dimensions of industrial structure optimization. The estimated coefficients of digital inclusive finance on the advanced and rationalized industrial structure are divided into 0.459 and 0.381, and all of them are significant at the 1% level, indicating that digital inclusive finance can significantly promote the adjustment and optimization of the industrial structure, and promote the development of the industrial structure towards rationalization and advanced upgrading. In addition, when the two sub-dimensions of digital inclusive finance and industrial structure optimization are regressed at the same time, the results are significantly positive, and the regression coefficient of digital inclusive finance decreases significantly compared with the baseline regression results, which means that the two sub-dimensions of industrial structure optimization play a partly intermediary role in digital inclusive finance and regional green innovation, and Hypothesis 5 is verified.

With the continuous integration and development of digital inclusive finance, a new round of transformation and upgrading of industrial structure will be driven by it. It will continue to eliminate "high-pollution" and "high-energy-consumption" industries, reduce energy loss and environmental pollution, thereby improving the efficiency of green innovation and promoting regional green innovation.

Table 7. Results of the intermediary mechanism test1

variant	return to baseline	Advanced industrial structure		Rationalization of industrial structure	
	(1)	(2)	(3)	(4)	(5)
	Regional Green Innovation	Advanced industrial structure	Regional Green Innovation	Rationalization of industrial structure	Regional Green Innovation
Core explanatory variables	0.658***	0.459***	0.583***	0.381***	0.612***
	(8.72)	(17.98)	(10.28)	(5.38)	(9.12)
intermediary variable	-	-	0.163***	-	0.121***
	-	-	(4.47)	-	(2.86)
constant term	-0.862	-2.572***	-1.332	-4.292***	-1.552
	(-2.19)	(-7.74)	(-1.68)	(-3.39)	(-1.28)
control variable	contain	contain	contain	contain	contain
Time & City	contain	contain	contain	contain	contain
R^2	0.656	0.549	0.659	0.272	0.677
aggregate effect	-	0.658		0.658	
intermediary effect	-	0.075		0.046	
direct effect	-	0.583		0.612	
item count	2513	2513	2513	2513	2513

5. Research Findings and Policy Recommendations

In the context of promoting green transformation, digital inclusive finance deeply fits the need for finance in the development of green innovation, and is an important entry point to further explore the value of green innovation. According to the data analysis in the previous section: in the analysis of the effect of digital inclusive finance on regional green innovation and the multiple linear regression model, it can be seen that there is a significant positive correlation between digital inclusive finance and regional green innovation, and the conclusions are still robust after a variety of robustness tests; in the test of heterogeneity, it is found that through the test of regional heterogeneity, digital inclusive finance has a promotional role for green innovation in different regions, and plays different roles according to the differences in the level of regional economic development; in the test of heterogeneity, it is found that digital inclusive finance has a promotional role for green innovation in different regions. In the heterogeneity test, the test of regional heterogeneity finds that digital inclusive finance has a role in promoting green innovation in different regions, and plays different roles according to the differences in the level of regional economic development; in the analysis of the intermediary effect mechanism, through the analysis of the three intermediary variables of the optimization of industrial structure, the innovation activity and the financing constraints, it is found that they have a positive and significant influence in the effect of digital inclusive finance on the green innovation of the region.

Based on the above conclusions, the paper makes the following recommendations:

First, promoting the stable development of digital inclusive finance, vigorously building and improving supporting equipment and systems for digital inclusive finance, actively promoting the development and improvement of digital infrastructure, and optimizing the basic environment. Second, strengthen the application of digital inclusive finance in the field of green innovation, and actively utilize the advantages of digital finance to guide the flow of capital from high-pollution industries to low-pollution and green sectors. Third, formulate development strategies according to local conditions. Eastern regions with perfect digital infrastructure and better financial environments should focus on expanding the depth of application of digital inclusive finance; central and western regions with lower levels of economic development and low efficiency in developing digital

inclusive finance should improve their financial systems and supporting facilities, actively build service platforms, and expand the degree of digitization and breadth of coverage. Fourth, the government can accelerate the upgrading and transformation of traditional industries, promote the healthy development of green industries, guide the upgrading of industrial structure, and enhance the innovation and R&D drive of enterprises by coordinating relevant policies.

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