

The Impact Effect of Digital Finance on Green Innovation

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Abstract. In recent years, the explosive growth of digital finance has compensated for the disadvantages of traditional finance. Additionally, it has contributed to the advancement of the green innovation system. In order to build a model of how digital finance affects green innovation, the paper uses panel data from 283 prefecture-level Chinese cities between 2011 and 2019. By analyzing regional location and the heterogeneity of urban development, we explore the degree of impact of digital finance and the path to achieving it. We also look at the characteristics of the function that digital finance plays in the economies of Sichuan, Chongqing, Beijing, Tianjin, and Hebei. The conclusions indicate that (1) The eastern region is where the impact of digital finance on green innovation is greatest, while the central and western regions are where it is weaker. (2) the impact path of digital finance on green innovation in cities is mostly through the depth of use, followed by the degree of digitalization and the breadth of coverage of cities.

Keywords: Digital Finance, Green Innovation, Heterogeneity Analysis.

1. Introduction

1.1 Background

At a time when economic development and environmental protection are at odds, green development is undoubtedly the new balance point for the issue of "harmony between man and nature". Obviously, innovation is the core driver of development. Green innovation is a creative fusion of development and innovation to boost environmental performance and promote green economic development. Therefore, many countries and regions have been investigating green innovation in recent years, and China is also implementing a development strategy for green innovation. However, China started its development plan for green innovation later than other countries, and pertinent research is still being refined.

The frontier issue of research is how to develop and improve green innovation capability. Compared with traditional innovation, green innovation requires more innovation resources continuously due to its higher innovation cost and more difficult innovation process, which makes the whole process of green innovation inseparable from the financial system's strong support and effective guarantee. Although traditional finance has made a lot of policy guidance, its effect on supporting green innovation is still very modest due to its structural issues. However, digital finance, which rides on the wave of the times, can not only make up for the weakness of traditional finance in practice through its advantages of network platform, digital technology, and universal access to the public, but also derive different financial functions, green attributes and other new models based on the original functions of traditional finance.

The structure of this paper is as follows: the first part introduces the policy background and compares the existing literature around digital finance and green innovation; the second part introduces the model construction and data sources; the third part analyzes the impact of digital finance on green innovation, followed by a series of robustness analysis, as well as further exploring the dynamic effects and realization paths of the impacts, sub-city regions and economic circles

Heterogeneity analysis; the last part is the conclusion summary of the paper based on the structure of the empirical analysis and the corresponding policy recommendations.

1.2 Literature Review

Digital finance refers to a new financial service formed by the use of developed scientific and technological means, such as the Internet, big data, cloud computing and so on, combined with traditional finance [1]. It enhances the service efficiency and service quality of financial institutions by empowering financial products, improving business processes, broadening the boundaries of financial services, improving business scenarios, etc. through technological means [2]. It can be seen that firstly, digital finance provides a more advanced and convenient environment for green innovation. Secondly, it reduces the transaction costs and default risks arising from information asymmetry, which greatly improves the feasibility of financial inclusion [3] and provides a guarantee for innovation. Besides, digital finance has lowered the threshold for small and micro businesses, poor and low-income groups to access financial services. On the other hand, it realizes the effective docking between the supply and demand of funds. This reduces financial exclusion, promotes household consumption, promotes innovation and entrepreneurship [4], and injects vitality into green innovation. The existing research has the following three aspects for the connection between digital finance and green innovation.

The first aspect is to analyze the two from the perspective of macro policy. The conclusion of the study is that, in general, the digital finance comprehensive index and each dimension index have obvious direct incentive impact on the improvement of regional innovation ability. It is a new driving force to improve the new kinetic energy of regional innovation, while showing good robustness. The difference lies in the heterogeneity of the digital finance innovation effect and the indirect mechanism of action [5]. The second aspect is to elaborate the relationship between digital finance and enterprise technological innovation from the micro level. Specifically, digital finance plays an important role in reducing factor cost and improving the efficiency of resource allocation, as well as the role of digital finance in green innovation and general technological innovation is different. [6]. The third dimension is to explore the moderating role of digital finance on the promotion of green innovation at the city level from the city dimension, and also to analyze the theoretical mechanism of how these two factors affect the high-quality development of cities. Some scholars also point out that the function of green innovation among promoting high-quality urban development is relatively limited [7].

In summary, the link between both digital finance and green innovation has been relatively richly discussed and studied by scholars. However there is still something that can be added. Compared with previous studies, the possible contributions of this paper include (1) To construct the effect model of digital finance on green innovation. Further discuss the degree of impact of digital finance on green innovation and implementation path. (2) In-depth study of regional differences, heterogeneity analysis of different city regions and economic circles and innovative research on the characteristics of the role of digital finance in economic circles.

2. Study design

2.1 Model Construction

Based on the above theoretical derivation and development, the impact effect of regional digital finance on regional green innovation is explored. The regression model constructed is as follows:

$$Y_{it} = \beta_0 + \beta_1 DF_{it} + \beta_3 \sum Z_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (1)$$

Y_{it} denotes the level of green innovation in region i in year t , DF_{it} denotes the digital financial inclusion index in region i in year t , μ_i denotes region fixed effects to capture other regional characteristics that do not change over time; τ_t denotes year fixed effects to control for unobservable

influences that change over time; ε_{it} denotes the random error term; $\sum Z_{it}$ denotes other control variables that affect the dependent variable, including the inclusion of foreign investment (for_inv), urbanization (urban), economic development (lngdp), industrial development (ind_dev), fiscal expenditure (fis_exp), science and technology expenditure (sci_exp), traditional financial development (fin_dev), fixed asset investment (fix_inv), transportation infrastructure (infra), and human capital (human).

2.2 Data sources

This paper constructs an empirical study using panel data from 283 cities in China, with the sample spanning 2011-2019. The data sources are described as follows. The variable definition is shown in Table 1.

Explanatory variable: Green innovation (GI), using the green patent applications of cities as a percentage of the total annual local applications to measure the level of green innovation. Referring to the IPC Green Patent List released by the World Intellectual Property Organization (WIPO) in 2010, the green patent applications of cities are identified by the environmental technology fields corresponding to the International Patent Classification.

Core explanatory variables: digital finance (DF), measured using the Digital Inclusive Finance Index of Peking University published by the Digital Finance Research Center of Peking University. Among the digital finance measures include digital inclusive finance index, depth of use (DF_DEPTH), breadth of digital finance coverage (DF_SPAN) and degree of digitization (DF_DIGITAL).

Table.1. Variable Definition Table

category	Symbols	Variables	Definitions
Explanatory variable	GI	Green Innovation	the number of green invention applications accounted for the number of regional applications in the year
Core explanatory variables	DF	Digital Finance	include digital inclusive finance index, depth of use, breadth of digital finance coverage and degree of digitization
Control variables	for_inv	Inclusion of Foreign Investment	the amount of actual foreign investment utilized in the city as a share of GDP
	urban	Urbanization	the proportion of urban construction land area to the administrative area of the city
	lngdp	Economic Development	the GDP per capita of the city
	ind_dev	Industrial Development	the sum of the proportion of output value of primary industry*1, the proportion of output value of secondary industry*2 and the proportion of output value of tertiary industry*4
	fis_exp	Fiscal Expenditure	the ratio of the city's fiscal output to GDP
	sci_exp	Science and Technology Expenditure	the ratio of the government's fiscal expenditure on science and technology

fin_dev	Traditional Financial Development	the balance of RMB loans of financial institutions as a proportion of GDP
fix_inv	Fixed Asset Investment	the gross fixed investment per capita
infra	Transportation Infrastructure	the road area per capita in the city
human	Human Capital	the number of university students per 100 people in the city

3. Results

3.1 Analysis of baseline regression results

Table 2 shows the results of the benchmark regressions of the impact of digital finance on green innovation, where column (1) is a fixed-effect regression without control variables, column (2) is a fixed-effect regression with control variables, column (3) is a two-way fixed-effect regression, and column (4) is a mixed regression with control variables. At the 5% level of significance, there is a substantial correlation between the digital finance regression coefficients. And the regression coefficients are positive. Therefore, we can preliminarily judge that digital finance has a facilitating effect on green innovation. The level of green innovation also rises in direct proportion to the degree of digital finance.

Table.2. Benchmark Regression Results for the Impact of Digital Finance on Green Innovation

variables	(1)	(2)	(3)	(4)
DF	0.0132***	0.0025**	0.0229***	0.0052***
t	(9.11)	(0.94)	(1.06)	(4.47)
N	2543	2543	2543	2543
R ²	0.0355	0.0519	0.1004	0.0261

Note: Values in parentheses are t-statistics of coefficients; ***, **, * indicate statistical values significant at 1%, 5%, and 10% significance levels, respectively; same below.

3.2 Robustness tests

For the reliability of the results of this study and to avoid chance, we first performed a data truncation process. Eliminating the influence of outliers on the measurement results. Table 3 presents the findings. All indicator variables are treated with 1% bilateral tail reduction. It mitigated the impact of extreme change on the results. Secondly we randomly selected 55% of the data for the econometric regression. Then, we reselected the variables temporally, taking 2015 (the year of establishment of Peking University Digital Finance Research Center) as the dividing line for data processing to avoid statistical errors. In addition, we replaced the original "percentage of green patent applications" with "number of green patent applications" and estimated again. According to the findings, the regression coefficients of the above robustness test are slightly higher than those of the previous benchmark regression, which indicates the robustness of the benchmark regression and further verifies the enabling effect of digital finance on green innovation.

Table.3. Robust Regression Results on the Impact of Digital Finance on Green Innovation

variables	(1)	(2)	(3)	(4)
DF	0.0030**	0.0367***	0.0305***	5.2096***
t	(1.10)	(6.64)	(3.91)	(14.31)
N	2543	1415	1132	2543
R ²	0.0515	0.1307	0.0908	0.1717

3.3 Test for endogeneity

In the empirical regression equation, there may be some endogeneity problems like omitted variables and reverse causality. The problem of endogeneity caused by omitted variables is solved by two-stage least squares regression with instrumental variables. Table 4 shows the results of endogeneity test. First, the core explanatory variables of digital finance lag phase I and lag phase II are respectively taken as the instrumental variables of current digital finance, and the two-stage least squares regression of instrumental variables is carried out. The results are shown in columns (1) and (2). The regression results show that there is no weak instrumental variables and over-identification problem. Besides, the selection of instrumental variables is effective. After adopting the instrumental variable method to reduce the endogeneity problem, the enabling effect of digital finance on green innovation is still significant. Meanwhile, the regression coefficients are improved to some extent compared with the original baseline regression.

Table.4. Endogeneity Test Results on the Impact of Digital Finance on Green Innovation

variables	(1)	(2)
DF	0.0152***	0.0285***
t	(5.29)	(8.13)
N	2260	1977
R ²	0.0442	0.0707

3.4 The dynamic effect of digital finance on green innovation and its implementation path

3.4.1 Dynamic path of the impact of digital finance on green innovation

Table 5 shows the dynamic impact of digital finance on green innovation, where columns (1) to (4) show the regression results of digital finance index lag phase 1 to 4 on the level of green innovation. The lag of the independent variable helps to improve the endogeneity problem. At the same time, it is observed that the coefficients of lag period 1 to 4 are 0.0111, 0.0219, 0.0248 and 0.0248, respectively. It is shown that the coefficient slowly rises, and as digital finance develops, so does the level of promotion for green innovation.

Table.5. Dynamic Effects on the Impact of Digital Finance on Green Innovation

variables	(1)	(2)	(3)	(4)
DF	0.0122**	0.0226***	0.0257***	0.0257***
t	(4.23)	(7.69)	(8.06)	(7.24)
N	2260	1977	1694	1411
R ²	0.0916	0.1560	0.1546	0.1365

3.4.2 The realization path of the impact of digital finance on green innovation

Aimed at further analyzing the impact path of digital finance on green innovation, we decompose digital finance into coverage breadth, use depth and digitization degree of digital finance, where columns (1) to (3) respectively represent coverage breadth (DF_SPAN). Regression results of DF_DEPTH and DF_DIGITAL on green innovation level. According to the results in the table 6, the application depth of digital finance has the greatest impact on green innovation, followed by the degree of digitalization and finally the coverage breadth. At the present stage, the deep use of digital finance directly supports the long-term and high-intensity development of green finance. Meanwhile, the increasing degree of digitalization makes digital finance more advanced and diversified, which provides the basis for technological innovation of green finance. Finally, breadth of coverage provides a more friendly environment for green innovation.

Table.6. Realization Path on the Impact of Digital Finance on Green Innovation

variables	(1)	(2)	(3)
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DF_SPAN	0.0020* (0.68)		
DF_DEPTH		0.0072*** (2.87)	
DF_DIGITAL			0.0052** (4.27)
N	2543	2543	2543
R ²	0.0511	0.0544	0.0424

3.5 Heterogeneity analysis by urban region

This paper studies whether the difference of regional location and urban development will lead to different effects of digital finance on green innovation.

So sample data is divided into three regions, east Midwest and on the basis of a new line of city institute issued 2020 city commercial charm list the sample about the present situation of urban development is divided into super one line, one line and two line city samples, respectively to pratt & whitney financial index, coverage, the use of depth and perspective of digitized four regression analysis. Table 7 shows the results of heterogeneity analysis by East-West Region.

From the point of view of regional differences, the promotion effect of digital finance on green innovation in the eastern region is significantly better than that in the central and western regions. In particular, the correlation coefficient of digital finance on green innovation in the western region is negative, which plays a certain inhibitory role. This indicates that the high quality development degree of digital finance in the western region is not enough to fully support the development of green innovation, and the positive regulation effect in the western region is limited.

The eastern region is the leading region of economic and technological development, with Beijing and Shanghai in recent years and the relatively good development of green innovation level, the scope of financial services is relatively wide and financial accessibility is relatively high. The positive role of digital finance is constantly permeating into green innovation. Compared with the central and eastern regions, most of the western regions are still underdeveloped, financial resources are scarce, the cost of financial services is high, and digital finance has not fully played its role. Moreover, due to geographical limitations, the positive role of digital finance in green innovation and development is difficult to show, and even appears to be inhibited.

From the perspective of urban development, the higher the degree of urban development, the stronger its promoting effect. The economic development of different regions is not balanced, and the breadth and depth of digital finance are different, which makes the impact of digital finance on the development of green innovation different.

Table.7. Heterogeneity Analysis by East-West Region

variables	EAST	MID	WEST	SP_FIRST	FIRST	SECOND
DF	0.0133*** (4.49)	0.0020* (0.43)	-0.0171* (-2.51)	0.0412** (5.28)	0.0133*** (4.67)	0.0057** (1.47)
DF_SPAN	0.0113*** (3.46)	0.0001** (0.02)	-0.0179*** (-2.46)	0.0329* (3.26)	0.0135*** (4.18)	0.0015* (0.36)
DF_DEPTH	0.0167** (6.21)	0.0067** (1.59)	-0.0097** (-1.51)	0.0319*** (5.60)	0.0149*** (5.69)	0.0110*** (3.16)
DF_DIGITAL	0.0105*** (8.10)	0.0073** (4.30)	-0.0034** (-1.07)	0.0292*** (5.01)	0.0089*** (4.07)	0.0031** (1.18)

3.6 Heterogeneity analysis of each economic circle

We further analyze the economic circle. Columns (1) to (4) are Chengdu-Chongqing economic circle, Beijing-Tianjin-Hebei economic circle, Yangtze River Delta economic circle and Pearl River Delta economic circle. The influence of digital finance on green innovation level in the Yangtze River Delta economic circle is stronger than that in the Pearl River Delta, followed by Beijing-Tianjin-Hebei economic circle and Chengdu-Chongqing economic circle. The situation in the Chengdu-Chongqing economic circle is similar to that in the western region above, with negative correlation coefficients, low popularization of digital finance and lagging development of blockchain, big data and other technologies. In the case of underdeveloped digital finance, its impact on the development of green innovation is temporarily uncertain.

The Yangtze River Delta has a significantly higher promoting effect than other economic circles. This may be because of the relatively developed digital finance in the Yangtze River Delta, the perfect information infrastructure, and the aggregation of innovation factors, which makes the promotion very obvious.(The details of this paragraph are shown in table 8.)

Table.8. Heterogeneity Analysis of Sub-economic Circles

variables	(1)	(2)	(3)	(4)
DF	-0.0095** (-0.78)	0.0084* (0.89)	0.0179*** (9.25)	0.0096*** (2.79)
DF_SPAN	-0.0186** (-1.41)	0.0027** (0.26)	0.0197*** (9.07)	0.0093*** (2.48)
DF_DEPTH	0.0124* (0.99)	0.0017** (1.95)	0.0189*** (10.32)	0.0101*** (3.14)
DF_DIGITAL	-0.0090** (-1.28)	0.0034** (0.55)	0.0109*** (7.51)	0.0079*** (2.75)

4. Conclusion and Enlightenment

4.1 Research Conclusions

In order to perfect the study on influencing factors of regional green innovation, this paper deeply analyzes the influence and effect of regional digital financial index and related characteristic indicators on promoting regional green innovation and its realization path.To give empirical support for raising the level of regional green innovation and fully using the role of digital finance in fostering regional green innovation, the main issues and shortcomings in regional green innovation development are examined. The main conclusions of this paper are as follows:

(1) Digital finance can effectively improve the level of green innovation, and as this industry develops, so will its ability to support green innovation. (2) The effects of digital finance are more noticeable in the eastern region than in the central and western regions, and the effect of the use depth of digital finance is stronger than the degree of digitalization and the coverage breadth. The research results of Sichuan, Chongqing, Beijing-Tianjin-Hebei and other economic circles also serve to better support this conclusion.

4.2 Policy Insights

The policy implications of this paper are in reaction to the aforementioned findings.

(1) Guaranteeing a favorable financial environment. The advantages of digital finance can be fully utilized to reduce information asymmetry, solve the problem of financing constraints, and provide guarantee for green innovation.While strengthening the integration of big data with cloud computing and other technologies, the government will formulate reasonable policies to ensure that digital

finance meets the needs of green innovation to the maximum extent and provide funds for research and development. A good financial environment can better play the role of digital finance and then enhance green innovation.

(2) Improving the imbalance of regional development. According to our analysis, Due to obvious regional differences, the impact of digital finance on green innovation is greater in regions with higher economic development and more advanced technological infrastructure. Additionally, the impact path of digital finance is mostly different in different regions, and the development strategy of digital finance needs to be adapted to local conditions. There should also be differences for how to dynamically realize the path.

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