Advances in Management & Applied Economics, Vol. 13, No. 3, 2023, 163-187
ISSN: 1792-7544 (print version), 1792-7552(online)
https://doi.org/10.47260/amae/1336
Scientific Press International Limited

Can Digital Financial Inclusion Affect Green Development? An Empirical Analysis Based on China's Provinces

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Abstract

In the information age, how to release the positive effect of finance on green economy is a question that needs to be answered in the modern society. Using the panel data of 30 provinces in China from 2011 to 2020 as the research sample, we evaluate the impact of digital financial inclusion on green development by calculating green total factor productivity. The results show that: Digital financial inclusion can promote regional green development significantly. This finding still remains valid after robustness tests. Moreover, the contribution of digital financial inclusion to green development is mainly reflected in technological advancement. While the positive impact of each dimension of digital financial inclusion on green development is also different, showing a decreasing trend in terms of coverage breadth, usage depth and digitalization. In further analysis, from the perspective of industrial structure optimization and scientific and technological innovation, we find that digital financial inclusion can improve the green development by increasing the rationalization and advancement of industrial structure as well as driving technological innovation. Using the panel threshold model, we find that there are double thresholds for industrial structure rationalization as well as three thresholds for technology innovation, digital financial inclusion displays a non-linear impact on green development.

JEL classification numbers: G20, O31.
Keywords: Digital financial inclusion, Green development, Green total factor productivity, Industrial structure, Technological innovation.

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Article Info: *Received:* March 3, 2023. *Revised*: March 27, 2023.
Published online: March 31, 2023.

1. Introduction

1.1 Background of the Study

While industrialization promotes economic and social progress, it also puts a significant pressure on the environment. China has proposed the green development idea of "man and environment living in harmony" in order to build a system of economic and social growth that aims for efficiency, peace, and sustainability. During the 40 years of reform and opening up, China’s economy has undergone remarkable change. The benefits of economic progress should not only be reflected in higher material living standards, but also in cleaner air, safe water and more beautiful living environment. Digital financial inclusion, which has emerged as the result of the internet, big data, cloud computing and other technologies, plays an important role in China's financial sector, it increases the possibility of access to financial services for remote groups, youth and women, provides sufficient financial assurance for the innovation and entrepreneurship for enterprises (Cai and Zhu, 2020), and significantly encourages economic growth (Qian et al., 2020), regional innovation (Liang and Zhang, 2019), and income distribution (Xiaoling Song, 2017), the value of digital financial inclusion for both social and economic development has been acknowledged. The popularity of green development is not only a profound reflection made by human beings in the face of the severe ecological environment, but also a desire and pursuit of sustainable development. The goal of "achieving carbon peaking by 2030 and carbon neutrality by 2060" places higher expectations on China's economic development. The primary track of the next phase of industrial revolution is digital transformation. The innovation of digital financial inclusion in the financial sector, supported by digital technology, has reshaped the service scenes of conventional finance, which will empower green growth with features such as sharing, convenience and low cost.

1.2 Literature Review

Many relevant studies on digital financial inclusion have been undertaken by scholars. Scholars believe that digital financial inclusion narrows the income gap between urban and rural residents (Park and Mercado, 2015), increases total factor productivity (Hou and Li, 2020) and supports industrial structure optimization and upgrading (Tang et al., 2019). Green development is impacted by many factors, such as industrial structure (Li and Su, 2016, Liu and Wei, 2020, Xuesheng Zhang, 2022), financial aggregation (Cao and Yu, 2018, Yuan et al., 2019), technology and scientific progress (Huang, 2017, Wang et al., 2017), opening to the outside world (Huang and Wu,2021, Zhou and Zhang, 2021) and so on. There is a “U-shaped” relationship between environmental regulation and green development, when environmental regulation becomes more stringent, green development will first decline and then rise (Li and Yi et al., 2020). Digital financial inclusion has green characteristics, the digitization, intensification and interconnection of its business models can effectively reduce energy consumption in the process of providing financial services (Duan et al., 2021). Fang and Yang (2021) find that financial technological improvements can reduce environmental pollution in urban areas, and this impact is greater within polluted, less economically developed and marginal cities. Based on the data from 283 cities, Xu et al. (2021) examine the relationship between digital financial inclusion and pollution reduction, concluding that digital financial inclusion can reduce carbon emissions by influencing enterprise innovation and entrepreneurship as well as improving industrial structure. By increasing the effectiveness of funding and encouraging green technological innovation, Lv et al. (2021) note that digital financial inclusion makes the industrial become more environment-friendly.

Just several theses have discussed the essential link between digital financial inclusion and green development. Can digital financial inclusion give green development more power? With the previous context, we will explore the connection between digital financial inclusion and green development from the perspective of provinces. The innovations of this paper may be as follows: Firstly, we explore the incentive effect of digital financial inclusion on green development, providing a new perspective for subsequent academic research. Secondly, from the perspectives of industrial structure optimization and technology innovation, we detail the specific mechanism of digital financial inclusion impact on green development, present policy suggestions that might be used to encourage the comprehensive combination of real economy with digital financial inclusion. The subsequent chapters of this article are as follows: Theoretical mechanism and research hypotheses are presented in Section 2, the research design is presented in Section 3, the empirical analysis is presented in Section 4, and the conclusions and implications are presented in Section 5.

2. Theoretical Mechanism and Research Hypotheses

2.1 The Direct Impact of Digital Financial Inclusion on Green Development

Digital financial inclusion has a positive impact on green development. Firstly, the inclusiveness of digital financial inclusion provides financial security for small and medium-sized enterprises (MSMEs). Conventional financial services favor large businesses with substantial assets, due to the lack of real assets and guarantee, MSMEs usually have a hard time to gain effective financial service support from financial institutions, which limits their ability in innovation and growth (Wan et al., 2020). Using digital technology, digital financial inclusion evaluates MSMEs' credit quickly and accurately, raises the likelihood that businesses could be eligible for bank loans and financing, which may enable MSMEs to realize technological innovation and support environmental improvements consequently. According to the information from central bank, China's total green loan balance in local and foreign currencies was 15.9 trillion yuan in 2021, climbing 33% of the previous year, deepening fintech support for green loans in the clean energy industry is expected to be a future trend of digital financial inclusion. Secondly, platformization of digital financial inclusion enables users to participate in environmental protection in more scenarios. Let's take Ant Forest as an example: Through online payments, customers can plant a virtual tree in the application interface, while a real tree will then be planted in the desert area. From the data released by the ministry of ecology and environment in 2021, we know that Ant Forest has planted 326 million trees and driven 613 million people to participate in online environmental charity activities. Thirdly, people have been able to redefine their eco-friendly lifestyles owing to the convenience of digital financial inclusion (Huang and Huang, 2018). Each trading platform has implemented programs for recycling, sorting trash, and second-hand sales, which cut down resource waste and make joint efforts with users to create green world.

Hypothesis 1*:* Digital financial inclusion plays an important role in achieving green development for regions.

2.2 Mechanism of Digital Financial Inclusion to Impact Green Development

According to the Environmental Kuznets Curve, when economic development reaches a certain level, structural effects and technological effects will be the two ways to improve environmental quality. Digital financial inclusion can support economic growth by improving the operational efficiency of the financial system, so that the structural and technological effects of economic growth can be released, which provides momentum for green development. Therefore, we choose to analyze the mechanism of digital financial inclusion affecting green development from two perspectives: industrial structure optimization and technological innovation.

Digital inclusive finance can promote industrial optimization and upgrading. Financial institutions absorb deposits to complete the initial accumulation of capital, adjust the quantity of capital factor inputs needed by enterprises, optimize the allocation of credit funds among industries and promote industrial structure upgrading in the process of digital financial inclusion development (Bruhn and Love, 2014). The diversification of financial products stimulates residential consumption, which also results in the modernization and restructuring of industrial structure. The industrial structure optimization has a positive effect on green development. Along with the transformation of economic growth momentum, large number of factors flow from secondary industries to tertiary industries, the flow of labor, capital and other factors among industries encourage the adjustment in industrial structure. Furthermore, with the innovation of the old production methods and the use of modern production methods, the product acquires green additional value, which contributes to the sustainable development of the economy.

Hypothesis 2: Digital financial inclusion improves regional green development by promoting industrial structure optimization and advancement.

Digital technologies can capture a large amount of data (Gomber et al., 2018), allowing digital inclusion to provide effective information for both the supply and demand of funds, as well as reduce transaction risk, and then create an ideal environment for business innovation (Demertzis et al., 2018). Green development can benefit from technological innovation. On the one hand, scientific and technological innovations have brought advanced environmental technologies that play an important role in protecting the environment. On the other hand, technological innovation has radically changed the traditional industrial development pattern that relies on labor and resources and produces green products with minimal pollution and energy consumption, which leads residents to develop green and sustainable lifestyles.

Hypothesis 3: Digital financial inclusion promotes regional green development by enhancing technological innovation.

3. Study Design

3.1 Sample Selection and Data Sources

Based on the contents and characteristics of digital financial inclusion scholars have established the framework for digital financial inclusion in various ways. Among these, the digital financial inclusion index, which is jointly compiled by Peking University and Ant Financial Services Group, has been widely recognized and used in research, it accurately and completely measures the development level of digital financial inclusion in each province, city and county in China. Because this data was released in 2011, so we took this year as the starting point for our study. Green development can be measured in three ways: Calculating green GDP, constructing a comprehensive index system and calculating green development efficiency. In this study, we choose the model based on the slack based measure (SBM) with directional distance function (DDF), and then combine with the Malmquist index (ML) to construct the green total factor productivity (GTFP) of each region to represent green development. Since the data for indicators of non-desired outputs in the GTFP are only updated until 2020, so our study is only available until 2020. It should be noted that Tibet, Hong Kong, Macau and Taiwan are not included in the study due to the serious lack of statistics. We selected a sample of 30 Chinese provinces from 2011 to 2020 for this study, with a total of 300 observations. The environmental data is sourced from the China Environmental Statistics Yearbook, the foreign direct investment data is sourced from the Wind database, the remaining data is sourced from the China Statistical Yearbook and Regional Statistical Yearbooks, finally, we use linear interpolation to fill in the vacant values.

3.2 Variable Design and Description

3.2.1 Explained Variable

Chung et al. (1997) combined the DDL with ML to calculate total factor productivity and introduced the concept of green total factor productivity. On this basis, Tone (2001) and others applied the SBM method to optimize the calculation of total factor productivity and got more accurate estimation results. Later, Oh (2010) constructed the GML index with transferability and accumulation, which made the measurement results more closely to the real condition. Referring to the studies of Zhao et al. (2020), Li and Xin (2020), we use the SBM-GML method to calculate green total factor productivity. The indicators involved in GTFP are selected as follows (Table 1).

Table 1: Input and output indicators of green total factor productivity

Indicator type	Indicator name	Indicator description
Input indicators	Labor	Number of employed
	Energy	Total energy consumption
	Capital	Total fixed capital formation
Output indicators	Expected	Real GDP
	Non-expected	Industrial wastewater discharge
		Industrial SO_2 discharge
		Industrial solid wastes discharge

<u>(1) Input indicators include labor factor, capital factor and energy factor</u>

The majority of reviewers used the amount of absolute employment to assess labor input, while Cui and Lin (2019) chose the average annual number of employees in firms, Liu and Xin (2018) chose the total number of employed people in the society at the end of year. In this thesis, we choose the number of people employed at the end of the year in each province to measure the input of labor factor.

Capital input is measured by the fixed capital stock of the whole society, which is estimated by the permanent inventory method with the year 2000 as the base period. Its calculation formula is as follows.

$$Cap_{it} = (1 - \delta_i)Cap_{i,t-1} + I_{it} \quad (1)$$

Cap indicates the fixed capital stock, δ indicates the capital depreciation rate (9.6%), I indicates the total fixed asset formation. Since the value of fixed asset investment is not updated after 2018, so we choose to use the growth rate of fixed asset investment to calculate the fixed capital stock from 2018 to 2020.

The energy factor is measured by total energy consumption.

(2) Output indicators include expected and non-expected output
Expected output is measured by real GDP (2010 as the base period). The emissions of wastewater, SO_2 and industrial solid wastes were selected to measure the non-expected output.
The calculation of the chain growth rate of green total factor productivity by region are shown in the Table 2. To obtain the absolute value of GTFP, we perform the following treatments: Let the value of green total factor productivity in 2010 as 1, then the absolute value of green total factor productivity in a given year is equal to the continuous product of 1 and the chain growth rate of the corresponding year. For example, $GTFP_{2012} = 1 \times GML_{2011} \times GML_{2012}$, we calculate the absolute values of technical progress (TC) and technical efficiency (EC) in the same way.

Table 2: Calculation of chained growth rate of GTFP for 30 provinces

PR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BJ	1.003	1.000	1.013	1.015	1.034	1.040	1.086	1.083	1.000	1.000
TJ	1.000	1.000	1.008	0.998	1.006	1.053	1.016	1.012	1.013	1.283
HE	0.998	0.997	0.999	1.002	1.008	1.011	1.031	1.023	1.035	1.121
SX	1.003	0.992	0.993	0.992	0.995	1.003	1.012	1.010	1.009	1.014
NMG	0.997	1.000	0.995	0.992	1.005	1.011	1.006	1.006	1.005	1.008
LN	0.996	0.997	1.001	0.997	1.006	1.005	1.014	1.027	1.029	1.015
JL	0.999	1.000	1.004	0.999	1.002	1.020	1.002	1.014	1.003	1.019
HLJ	1.001	0.986	0.997	1.004	1.003	1.011	1.008	1.005	1.011	1.017
SH	1.019	1.025	1.008	1.030	1.022	1.044	1.097	1.128	1.000	1.000
JS	1.018	1.022	1.022	1.023	1.024	1.029	1.052	1.055	1.172	1.000
ZJ	1.017	1.017	1.018	1.016	1.018	1.029	1.031	1.038	1.036	1.065
AH	0.998	0.998	0.998	0.998	0.998	1.004	1.004	1.002	1.014	1.024
FJ	0.996	0.996	1.000	0.997	0.999	1.002	1.018	1.013	1.016	1.037
JX	0.997	0.999	0.998	0.998	0.997	0.999	1.010	1.004	0.988	1.007
SD	1.013	1.014	1.022	1.012	1.010	1.017	1.031	1.029	1.034	1.070
HA	0.998	1.003	1.010	1.008	1.008	1.027	1.042	1.021	1.136	1.288
HB	0.997	0.997	1.003	0.998	1.000	1.019	1.022	1.025	1.025	0.997
HN	0.994	0.997	1.002	0.998	0.999	1.020	1.030	1.034	1.039	1.155
GD	1.145	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
GX	0.998	0.996	0.999	0.997	0.999	1.009	0.997	0.999	0.999	1.005
HI	0.887	0.970	0.993	0.958	1.010	1.210	1.000	1.000	1.000	1.000
CQ	1.003	1.003	1.007	0.999	1.002	1.024	1.002	1.008	1.007	1.011
SC	1.003	1.002	1.003	0.998	1.010	1.018	1.022	1.026	1.014	1.022
GZ	0.985	0.991	0.997	0.989	0.998	1.012	0.995	1.000	1.000	1.005
YN	0.991	0.999	1.001	0.996	0.998	0.997	1.014	1.000	0.997	1.004
SN	0.999	1.011	1.001	0.995	0.995	1.005	0.998	1.008	0.994	1.001
GS	0.985	0.996	0.994	0.995	0.998	1.016	1.004	1.003	1.006	1.018
QH	1.000	0.934	1.070	1.000	0.898	1.113	1.000	0.897	0.997	1.117
NX	0.949	1.005	0.986	0.988	0.992	1.017	1.007	0.990	1.004	1.336
XJ	0.988	0.989	0.987	0.995	0.997	1.011	0.997	1.005	1.000	1.003

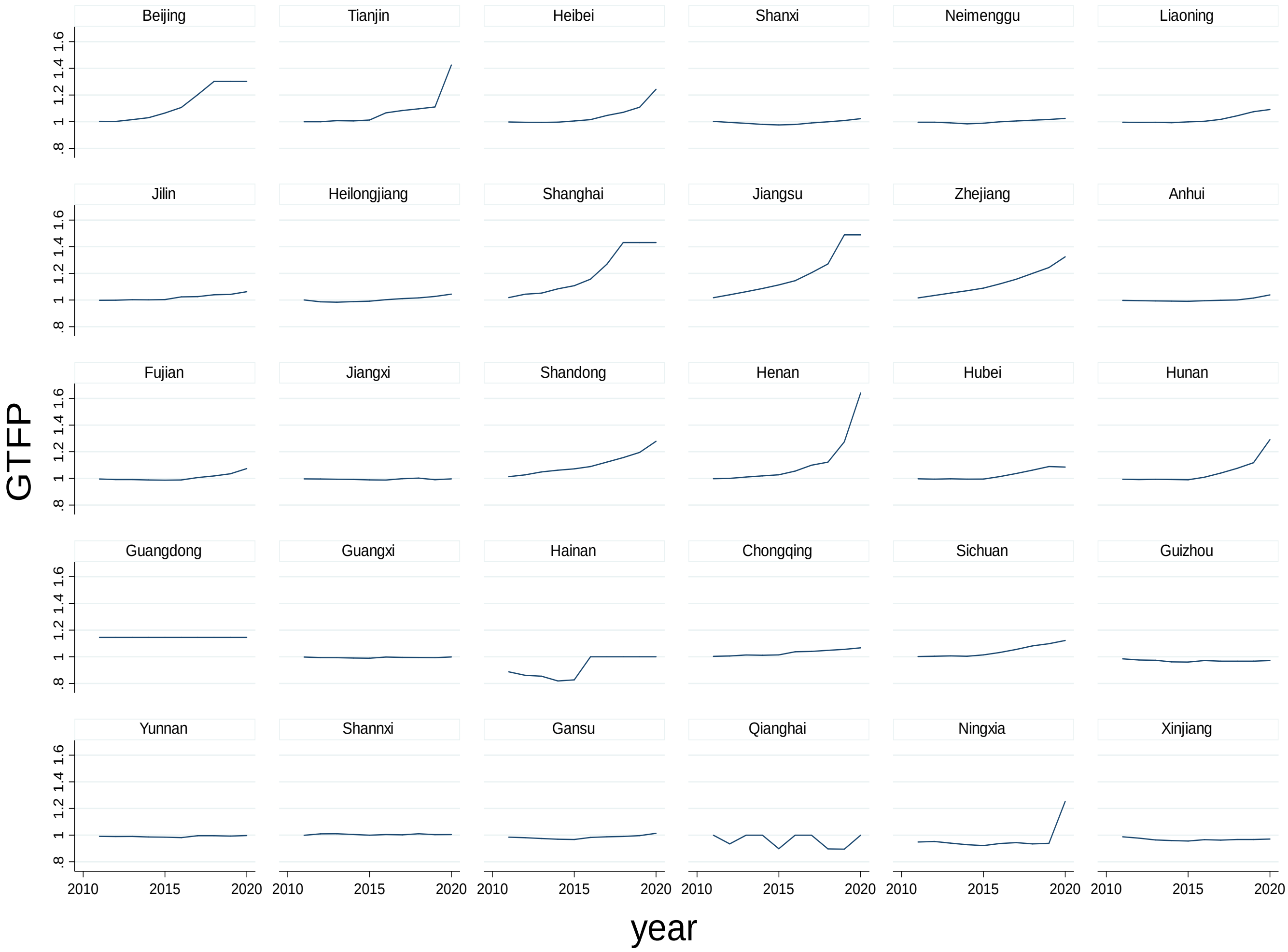

Figure 1: Time trends of GTFP in 30 provinces

The time series variation of green total factor productivity for each region is shown in the Figure 1. As we can see, Green total factor productivity in most provinces produced a significant change between 2016 and 2020. Since green development was elevated to the five major development concepts after the 18th National Congress, China has made many effective initiatives in environmental protection and regulation by promoting green production and resource conservation, which has provided the impetus for the development and transformation of green economy in China.

3.2.2 Explanatory Variables

The digital financial inclusion index is derived from finance research center of Peking University, which includes one primary indicator (*DFI*) and three secondary indicators: coverage breadth (*Cov*), usage depth (*Usa*) and digitization (*Dig*).

3.2.3 Mechanism Variables

(1) The effect of industrial structure optimization

The optimization of industrial structure includes the industrial structure rationalization and advancement. Rationalization of industrial structure refers to the coordination among industries, which requires the adjustment of the unreasonable industrial structure, so that resources can be reasonably allocated in various industries. Researchers generally use the structural deviation degree to measure the industrial structure rationalization, and the formula is:

$$E = \sum_{i=1}^{n} \left|\frac{Y_i/L_i}{Y/L} - 1\right| = \sum_{i=1}^{n} \left|\frac{Y_i/Y}{L_i/L} - 1\right| \tag{2}$$

E is structural deviation, Y is output, L is employment, i is industry and n is the number of industrial sectors. Y/L is productivity, Y_i/Y is output structure, L_i/L is employment structure. Classical economics argues that the economy will eventually reach balance, so Y_i/L_i equals Y/L, E equals 0. However, this index ignores the differences in the contribution of each industry on the economy during its calculation. On this basis, the Thiel index is optimized as follows:

$$Thiel\ index = \sum_{i=1}^{n} (\frac{Y_i}{Y_i})\ ln\left(\frac{Y_i/Y}{L_i/L}\right) \tag{3}$$

As previously stated, the economy reaches equilibrium when the $Thiel\ index = 0$. To simplify the subsequent analysis, we use $1/Thiel\,index$ to turn industrial structure rationalization into a positive indicator, indicated as *TL*.

The advancement of industrial structure is manifested by the emergence of new industries to replace the original industries, which is the process of transformation from junior industries to superior industries. In the process of industrial structure advancement, the growth rate of tertiary industry is faster than primary and secondary industry. We measure the industrial structure advancement by the percentage of tertiary sector output to secondary sector output, indicated as *TS*. The higher value of *TS*, the more advanced to the industrial structure.

(2) The effect of technological innovation

Innovation includes inputs, outputs and benefits. Inputs include human investment, capital investment and equipment investment. Outputs refers to the innovative products obtained through the use of production factors, such as patents and papers. Benefits refer to the economic and social rewards brought by innovation behavior, such as enterprise profits and the income from selling of new items. Since patent examinations will take a long time, the process from technology to product and then sales on the platform are easily disturbed by production costs, social acceptance and other factors. Therefore, we choose the patent application number to measure technological innovation, indicated as *Tech*.

3.2.4 Control Variables

Government actions, opening up, foreign direct investment, infrastructure building, human capital level and urbanization level are introduced as control variables in the regression. Where, government actions are expressed as the ratio of local general budget expenditures to regional GDP, noted as *Gov*. Foreign openness is expressed as the ratio of total imports and exports to regional GDP, noted as *Open*. Foreign direct investment is expressed as the ratio of foreign direct investment to regional GDP, noted as *Fdi*. Infrastructure development is expressed as per capita road area, denoted as *Road*. Human capital is expressed as the number of students in higher education per million people, denoted as *Edu*. Urbanization level is expressed as the ratio of urban population to total population, denoted as *Urban*.

Table 3: Definition of variables

Type	Name	Symbol	Definition
Explained variable	Green development	*Green*	SBM-GML for calculating green total factor productivity
Explanatory variables	Digital financial inclusion	*DFI*	from Peking University
	Coverage breadth	*Cov*	
	Use depth	*Usa*	
	Digitization	*Dig*	
Mechanism variables	Industrial structure rationalization	*TL*	$\frac{1}{\sum_{i=1}^{n}(\frac{Y_i}{Y_i})\ln\left(\frac{Y_i/Y}{L_i/L}\right)}$
	Industrial structure advancement	*TS*	$\frac{\text{Tertiary industry production}}{\text{secondary industry production}}$
	Technology innovation	*Tech*	Patent application number
Control variables	Government actions	*Gov*	$\frac{\text{General budget expenditures}}{\text{GDP}}$
	Opening up	*Open*	$\frac{\text{Total imports and exports}}{\text{GDP}}$
	Foreign direct investment	*Fdi*	$\frac{\text{Foreign direct investment}}{\text{GDP}}$
	Infrastructure construction	*Road*	Per capita road area
	Human capital	*Edu*	The number of students in higher education per million people
	Urbanization	*Urban*	$\frac{\text{Urban population}}{\text{Toal population}}$

3.3 Model Construction

In order to explore the correlation between digital financial inclusion and green development, we conduct a preliminary study employing the following regression:

$$Green_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{4}$$

$$EC_{it} = \alpha_2 + \beta_2 DFI_{it} + \theta_2 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{5}$$

$$TC_{it} = \alpha_3 + \beta_3 DFI_{it} + \theta_3 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{6}$$

i is region, t is time, $Green$ is green development measured by GTFP, EC and TC indicates technical efficiency and technical progress, DFI indicates digital financial inclusion, $Control$ is a set of control variables, λ is individual effect, μ is time effect.

Referring to the studies of Jiang (2022) and Tang (2022), the model below evaluated the link between the explanatory variable and the mechanism variables. Theoretical analysis was used to elaborate the relationship between the explained variable and mechanism variables, the relevant theory has been described in Chapter 2.

$$TL_{it} = \alpha_4 + \beta_4 DFI_{it} + \theta_4 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{7}$$

$$TS_{it} = \alpha_5 + \beta_5 DFI_{it} + \theta_5 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{8}$$

$$Tech_{it} = \alpha_6 + \beta_6 DFI_{it} + \theta_6 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{9}$$

TL, TS, $Tech$ indicates industrial structure rationalization, industrial structure advancement and technological innovation. Furthermore, taking a single threshold as an example, constructing the following threshold model.

$$Green_{it} = \tau_0 + \tau_1 DFI_{it} I(TL \le \gamma_1) + \tau_2 DFI_{it} I(TL > \gamma_1) + e_{it} \tag{10}$$

$$Green_{it} = \varphi_0 + \varphi_1 DFI_{it} I(TS \le \gamma_2) + \varphi_2 DFI_{it} I(TS > \gamma_2) + e_{it} \tag{11}$$

$$Green_{it} = \omega_0 + \omega_1 DFI_{it} I(Tech \le \gamma_3) + \omega_2 DFI_{it} I(Tech > \gamma_3) + e_{it} \tag{12}$$

4. Empirical Results and Analysis

4.1 Descriptive Statistics

Before analysis, we need to test whether there is multicollinearity between variables, the test results are shown in Table 4, the expansion coefficient of each variable is less than 10 which means there is no multicollinearity. The descriptive statistics of variables are shown in Table 5.

Table 4: Multicollinearity test

Variables	VIF	1/VIF
DFI	1.830	0.548
Gov	1.560	0.640
Open	3.440	0.291
Fdi	1.540	0.650
Road	1.500	0.665
Edu	2.560	0.390
Urban	5.430	0.184
MeanVif	2.550	

Table 5: Descriptive statistics

Variables	Mean	Variance	Min	Max
Green	1.038	0.103	0.819	1.641
DFI	0.217	0.097	0.018	0.432
Cov	0.198	0.096	0.002	0.397
Usa	0.212	0.098	0.007	0.489
Dig	0.290	0.118	0.008	0.462
Gov	0.251	0.104	0.110	0.643
Open	26.534	29.581	0.764	154.816
Fdi	2.015	1.690	0.010	10.093
Road	15.896	4.799	4.040	26.780
Edu	2.641	0.805	1.082	5.613
Urban	0.590	0.122	0.350	0.896
TL	0.099	0.128	0.013	1.266
TS	1.324	0.729	0.527	5.244
Tech	0.102	0.144	0.001	0.967

4.2 Regression Analysis

The influence of digital financial inclusion on green development is examined by two-way fixed effects model, the estimate results are shown in Table 6. As seen in the column (1) and column (2), the development of digital financial inclusion shows a significant positive impact on the green development, and the model fits better after the time-effect has been controlled. The estimated coefficient of *DFI* is 3.250, which is significant at the 1% level. Using *EC* and *TC* as explained variables, the regression results are shown in column (3) and column (4), digital inclusive finance still shows contribution to technological progress with a significance level of 1%, but technical efficiency has not appeared as such. This suggests that digital financial inclusion has an influence on green development primarily by improving the level of technology, however, under the current technological level, diverse resources have been unable to achieve acceptable allocation, and technical efficiency has not been able to become the major path to encourage green development. Technological progress is manifested as using the same input to achieve more output, which means the production technology frontier outward. Technological efficiency refers to achieve productivity enhancement under the existing technology level by increasing the factor coordination and optimizing resource allocation. The improvement of technological efficiency can reduce the loss caused by inefficient production and enhance the resource utilization in the process of technological progress, which provides momentum for economic sustainable development. The region should pay more attention to the improvement of technological efficiency and guide it to advance in the same frequency with technological progress, so as to release the promotion effect of digital financial inclusion for green development in a better way.

Table 6: Results of the impact of digital financial inclusion on green development

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	Green	***Green***	***TC***	***EC***
DFI	0.501***	3.250***	3.280***	0.414
	(0.115)	(0.780)	(0.887)	(0.522)
Gov	-0.344***	-0.091	-0.116	0.215*
	(0.113)	(0.107)	(0.148)	(0.123)
Open	-0.000	-0.001	-0.001	-0.0003
	(0.001)	(0.001)	(0.0005)	(0.0003)
Fdi	-0.007*	-0.011**	-0.012***	-0.001
	(0.004)	(0.004)	(0.004)	(0.002)
Road	-0.006**	-0.005**	-0.006***	0.001
	(0.003)	(0.002)	(0.002)	(0.002)
Edu	0.013	-0.003	-0.017	0.037
	(0.023)	(0.022)	(0.020)	(0.037)
Urban	0.061	-0.045	-0.142	0.055
	(0.148)	(0.160)	(0.144)	(0.190)
_cons	1.050***	1.035***	1.137***	0.830***
	(0.062)	(0.067)	(0.075)	(0.082)
Code	YES	YES	YES	YES
Year	NO	YES	YES	YES
Obs	300	300	300	300
R^2	0.335	0.566	0.591	0.156

note: *** means p<0.01, ** means p<0.05, * means p<0.1, standard errors in brackets.

Furthermore, the three secondary indicators of coverage breadth, usage depth and digitalization were regressed as core explanatory variables. The estimated results are shown in Table 7. Estimated coefficients of the three indicators in descending order are coverage breadth, usage depth and digitalization, the coefficient of coverage breadth is higher than other two indicators significantly, which indicates that the impact of digital financial inclusion on green development is mainly generated through the expansion of coverage breadth. "Inclusion" and "Universality" are the essential features of digital financial inclusion, which enables more groups to participate in financial activities. By merging individual resources and information, the financial system matches financial service with supply and demand, which is conducive to enhancing the operational efficiency of the financial system as well as the economy and society, and provides the basic safeguard for improving the economic development and green development. " Digitalization" is another important feature of digital financial inclusion. As the combination of technology and finance, the low-cost and high-efficiency features of digital financial inclusion reduce the cost and energy consumption in financial activities, which is the real value of digital financial inclusion for green development.

Table 7: Results of the impact of three secondary indicators of digital financial inclusion on green development

Variables	(2)	(3)	(4)
	Green	***Green***	***Green***
Cov	2.388**		
	(0.981)		
Usa		1.483***	
		(0.414)	
Dig			1.258***
			(0.375)
Gov	-0.310***	-0.148	-0.323***
	(0.104)	(0.113)	(0.097)
Open	-0.001	-0.001	-0.0002
	(0.001)	(0.001)	(0.001)
Fdi	-0.008**	-0.011**	-0.007
	(0.004)	(0.005)	(0.005)
Road	-0.008***	-0.005**	-0.007***
	(0.002)	(0.002)	(0.002)
Edu	-0.014	0.002	-0.013
	(0.020))	(0.021)	(0.018)
Urban	-0.065	0.118	0.268
	(0.174)	(0.153)	(0.165)
_cons	1.208***	1.007***	1.019***
	(0.073)	(0.082)	(0.072)
Code	YES	YES	YES
Year	YES	YES	YES
Obs	300	300	300
R^2	0.503	0.517	0.531

4.3 Robustness Tests

We choose to perform robustness tests by three ways: replacing the explained variable, replacing the explanatory variable and excluding some samples. We used green total factor productivity to symbolize green growth in the prior work. In this section, we select 15 indicators from three aspects: green economy, green society and green life, using the entropy method to construct a comprehensive index to remeasure the green development, indicators are shown in the Table 8. Because the indicator of environmental pollution treatment investment is revised only till 2018, so this part only includes 240 samples. The results are shown in the column (1) of Table 9, the estimated coefficient of digital financial inclusion on green development is still significantly positive after changing the measure of green development.

Table 8: 15 Indicators of the green development

Indicator layer	Specific indicators	Measurement method
Green economy	R&D funding investment	$\frac{\text{R\&D expenses}}{\text{GDP}}$
	Number of granted patent applications	/
	Foreign trade openness	$\frac{\text{Import and export total}}{\text{GDP}}$
	Foreign trade dependency	$\frac{\text{Foreign direct investment}}{\text{GDP}}$
	Urbanization rate	$\frac{\text{Urban population}}{\text{Toal population}}$
	Urban-Rural consumption coordination level	$\frac{\text{Consumer spending of urban residents}}{\text{Consumer spending of rural residents}}$
	Ratio of urban and rural disposable income	$\frac{\text{Disposable income of urban residents}}{\text{Disposable income of rural residents}}$
Green living	Forest coverage	/
	Exhaust emissions per unit of GDP	$\frac{SO_2\text{ emissions}}{\text{GDP}}$
	Wastewater emissions per unit of GDP	$\frac{\text{Wastewater discharge}}{\text{GDP}}$
	Environmental pollution treatment investment	$\frac{\text{Investment in environmental pollution control}}{\text{GDP}}$
Green society	Per capita education spending	$\frac{\text{Education funding}}{\text{Total population}}$
	Per capita number of health facilities	$\frac{\text{Number of health organizations}}{\text{Total population}}$
	Per capita of road miles	$\frac{\text{Road miles}}{\text{Total population}}$
	Per capita of park area	$\frac{\text{Park area}}{\text{Total population}}$

The widespread adoption of mobile payment services such as WeChat and Alipay is closely connected to the advancement of digital financial inclusion. As the carrier of online payment, the popularity of mobile phones will play a critical role in the development of digital financial inclusion. Therefore, we use the penetration rate of mobile phone to represent the development of digital financial inclusion, as shown in the column (2) of Table 9, the results stay consistent with the initial part. In the sample replacement section, considering that Beijing, Tianjin, Shanghai and Chongqing are different from other provinces in terms of administration scale, so we remove these four regions from the sample, the results are shown in the column (3), digital financial inclusion still has a remarkable positive impact on the green development.

Table 9: Results of robustness tests

Variables	(1) Replacing explained variable	(2) Replacing explanatory variable	(3) Excluding some samples
DFI	0.772***		2.647**
	(0.240)		(1.203)
Mobile		0.001**	
		(0.001)	
Gov	0.097	-0.473***	-0.018
	(0.069)	(0.116)	(0.116)
Open	-0.001***	-0.001	0.0002
	(0.0002)	(0.001)	(0.0009)
Fdi	0.007***	-0.006	-0.009**
	(0.002)	(0.004)	(0.006)
Road	0.002**	-0.008***	-0.004*
	(0.001)	(0.003)	(0.002)
Edu	-0.004	-0.015	0.016
	(0.012)	(0.019))	(0.031)
Urban	0.477***	0.097	-0.039
	(0.108)	(0.162)	(0.183)
_cons	0.013	1.148***	0.964***
	(0.050)	(0.060)	(0.081)
Code	YES	YES	YES
Year	YES	YES	YES
Obs	240	300	260
R^2	0.830	0.465	0.459

4.4 Mechanism Tests

In this section, we will examine the specific mechanism of digital financial inclusion affecting green development, and the regression results are shown in Table 10. Column (1) to column (3) show the results of the tests with *TL*, *TS* and *Tech* as mechanism variables, respectively.

Table 10: Results of the impact mechanism of digital financial inclusion on green development

Variables	(1)	(2)	(3)
	TL	***TS***	***Tech***
DFI	2.592***	5.414**	1.861**
	(1.006)	(2.269)	(0.858)
Gov	0.173*	2.175***	-0.172
	(0.093)	(0.547)	(0.126)
Open	0.0003	-0.007***	-0.001
	(0.001)	(0.003)	(0.001)
Fdi	-0.004	-0.024**	0.023**
	(0.003)	(0.011)	(0.012)
Road	-0.005***	-0.018*	-0.005
	(0.001)	(0.009)	(0.004)
Edu	-0.018	-0.016	0.034
	(0.020)	(0.107)	(0.030)
Urban	0.355***	1.268	-0.353
	(0.123)	(1.096)	(0.243)
_cons	-0.149***	0.182	0.167
	(0.056)	(0.524)	(0.131)
Code	YES	YES	YES
Year	YES	YES	YES
Obs	300	300	300
R^2	0.261	0.832	0.644

It can be seen that each unit increase in digital financial inclusion leads to 2.592 units increase in industrial structure rationalization, 5.414 units increase in industrial structure advancement and 1.861 units increase in technological innovation, all estimated coefficients are significant at the level of 10%. Through the above empirical analysis, the development of digital inclusive finance has a significant role in promoting the industrial structure rationalization, industrial structure advancement and scientific and technological innovation. Under the effect of industrial structure optimization, production factors get reasonable distribution, resource utilization rate is improved, traditional and new industries gradually form a sustainable development pattern, all of these have speeded up the process of regional green transformation. With the impetus of scientific and technological innovation, green industries show stronger competitiveness in the market, social production and lifestyle tend to be environment-friendly, and environmental supervision and management approaches have been developed and applied, providing a variety of ideas for achieving green development. Therefore, it can be considered that industrial structure optimization and scientific and technological innovation are two effective paths for digital financial inclusion to promote the green development.

4.5 Nonlinear Analysis

In the previous study, we got the conclusion that the development of digital financial inclusion can enhance green development positively and significantly. So, does this demonstrate that digital financial inclusion may encourage green growth at any stage? We have observed that industrial structure optimization and technological innovation are the key mechanism for digital financial inclusion to influence green development, and here, we chose to use the bootstrap method proposed by Hansen (1999) to test for the presence of thresholds by estimating 1000 samples of the three mechanism variables as threshold variables. First, we run the test with three thresholds, if the test passes, we think there should be three thresholds in the model, if not, we run the test with two thresholds and the test with one threshold in turn. The examination results of the threshold number are shown in Table 11. When *TL* and *Tech* are used as threshold variables, *DFI* shows a non-linear effect on green development, where *TL* has two thresholds and *Tech* has three thresholds. However, the *TS* has not passed any threshold test, so we have no reason to reject the original hypothesis that there are no non-linear effects of *DFI* on green development when *TS* is used as threshold variable.

Table 11: Test results for the number of thresholds after 1000 samples estimation

Variables	Threshold number	P value	Crit10	Crit5	Crit1
TL	Single	0.032**	39.117	51.526	72.356
	Double	0.020**	26.570	33.093	56.626
	Triple	0.494	41.899	55.762	90.375
TS	Single	0.266	38.937	48.905	67.775
	Double	0.168	36.1926	46.633	75.8779
	Triple	0.589	38.0668	44.7332	62.3268
Tech	Single	0.000***	35.714	42.591	56.336
	Double	0.060*	27.390	32.520	48.064
	Triple	0.079*	44.186	59.203	106.205

Table 12 shows the estimated values and confidence intervals of the thresholds when *TL* is used as the threshold variable. As shown in the table, the first value is 0.084 and the second value is 0.374.
Table 13 shows the regression results, when the *TL* is at lower level, *DFI* has a negative effect on green development, but it is not significant. As the industrial structure gradually evolves to a reasonable interval, *DFI* begins to show a positive effect on green development, and this effect becomes significant when the value of this indicator is greater than 0.374. The industrial structure rationalization can allocate production factors scientifically according to the needs of each industry under the existing resource and technology constraints, and the allocation effectiveness of financial resources among industries will also be enhanced, which is beneficial to the greater benefits released by digital financial inclusion in green development.

Table 12: Estimation results when TL as threshold variable

Threshold Number	Threshold Estimates	95% Confidence Interval
Single	0.084	[0.079, 0.088]
Double	0.374	[0.367, 0.378]

Table 13: Regression results when TL as threshold variable

Variables	Coefficient	Standard error	P value
TL≤0.084	-0.035	0.229	0.877
0.084<TL≤0.374	0.276	0.210	0.188
TL>0.374	0.769***	0.206	0.000
Gov	0.104	0.130	0.425
Open	-0.001	0.001	0.338
Fdi	-0.013***	0.005	0.009
Road	-0.009***	0.004	0.020
Edu	0.097*	0.057	0.092
Urban	0.350	0.460	0.447
_cons	0.723***	0.273	0.008

Table 14 and Table 15 show the threshold values and regression results with Tech as the threshold variable, the first threshold value is 0.111, the second is 0.176 and the third is 0.179. When the value of Tech is above 0.176, the regression coefficient of the impact of digital financial inclusion on green development is 3.7 times higher than when it is less than 0.176, this indicates the improvement of the technology innovation can make digital financial inclusion show the positive impact on green development better. When the value of Tech is greater than 0.179, the estimated coefficient decreases, which may be due to that technological innovation only shows an increase in the quantity, but does not effectively increase in the quality. This suggests that in the process of science and technology innovation, more attention should be paid to the practicality of innovation outputs.

Table 14: Estimation results when Tech as threshold variable

Threshold number	Threshold estimates	95% confidence interval
Single	0.111	[0.110, 0.112]
Double	0.176	[0.174, 0.177]
Triple	0.179	[0.177, 0.186]

Table 15: Regression results when Tech as threshold variable

Variables	Coefficient	Standard error	P value
Tech≤0.111	0.091	0.178	0.609
0.111<Tech≤0.176	0.452**	0.203	0.026
0.176<Tech≤0.179	1.673***	0.359	0.000
Tech>0.179	0.665***	0.225	0.003
Gov	0.283*	0.154	0.065
Open	-0.001	0.001	0.662
Fdi	-0.015***	0.004	0.000
Road	-0.007*	0.004	0.081
Edu	0.084*	0.043	0.052
Urban	-0.184	0.448	0.682
_cons	0.948***	0.205	0.000

5. Research Findings and Insights

5.1 Research Findings

Based on the literature and theories related to digital financial inclusion and green development, using the panel data of 30 provinces in China from 2011 to 2020 as the research sample, this thesis discusses the correlation between digital financial inclusion and green development in terms of direct effect, mechanism effect and non-linear effect by measuring digital financial inclusion and green development indicators.

The findings of the study are as follows:

(1) During the period from 2011 to 2020, the green total factor productivity in all provinces of China shows a growth trend, green development in most regions shows a noticeable enhancement after the “thirteenth five-year plan”.

(2) The dimensions of digital financial inclusion show diverse positive effects on green development, and the influence of coverage breadth, usage depth and digitization on green development decreases in order. The impact of digital financial inclusion on green development is mainly accomplished by expanding the coverage of financial services.

(3) The impact of digital financial inclusion on green development can be divided into two paths: optimizing industrial structure and promoting scientific and technological innovation.

(4) There are two threshold effects for the rationalization of industrial structure. As the industrial structure tends to the rationalization, digital financial inclusion starts to release significant positive benefits for green development.

(5) There are three threshold effects of science and technology innovation, with the continuous improvement of the technology innovation, the contribution of digital financial inclusion to green development will rise first and fall later.

5.2 Research Insights

Firstly, innovate financial services and stimulate the green attributes of finance. In the context of "Digital China" construction, guide the deep integration of information technology and financial industry, focus on expanding the breadth and depth of financial services, create diversified service scenarios and boost the quality as well as efficiency of financial services with digital technology. Using financial technology as a bond, build green financial technology system, promote the coordinated development of inclusive finance and green finance, so as to provide new momentum for green development.

Secondly, optimize the industrial structure and release the industrial green benefits. Regions should promote the green transformation of traditional industries to achieve cleaner and more efficient production processes. Accelerate the infrastructure construction of emerging industries, develop standards for green manufacturing and improve the supply of green products and services. Give full play to the role of digital infrastructure in improving the resource allocation efficiency and enhancing the transformation capacity of industrial structure.

Finally, strengthen scientific and technological innovation and promote the green transformations of development. Digital financial inclusion has improved the financing constraint dilemma of enterprises, but these financial supports have not been fully and effectively invested in the substantial innovation due to the limitation of the scale and development of enterprises. Regions can take appropriate financial means to provide direct financial subsidies to technology-based enterprises. At the same time, it should actively play the demonstration effect of green innovation enterprises, improve the landing system of innovation achievements and enhance regional environmental competitiveness.

There are still some shortcomings in this paper: The first one is that we use green total factor productivity to express green development, but this method may not describe green development completely. Green development has different meaning in different development stage, a more systematic and comprehensive index evaluation system needs to be explored and constructed in order to achieve an accurate interpretation of green development. The second point is that the synergy between digital financial inclusion and green finance has not been considered in this thesis. In the new stage of the digital financial inclusion, its interactive development with green finance may bring new ideas for the green transformation of the economy, and the synergy between green finance and digital financial inclusion in green development should be discussed further in the future.

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