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Digital Financial Inclusion, Financial Efficiency and Green Innovation

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Abstract: The financing difficulty of green innovation projects has always been an obstacle to enterprises' green innovation. Digital financial inclusion provides a new opportunity to solve the financing difficulty of green innovation. Based on the construction of a theoretical framework for digital financial inclusion to influence green innovation, this study empirically analyzes the impact and mechanism of digital financial inclusion on green innovation by using the provincial panel data of China from 2011 to 2020. The results show that digital financial inclusion has a significant positive impact on green innovation. The promotion effect of the development of digital financial inclusion on green innovation is mainly driven by the depth of digital financial inclusion use and the digitalization of financial inclusion. The results of the intermediary effect analysis show that digital financial inclusion can promote green innovation by alleviating capital misallocation and improving financial efficiency.

Keywords: digital financial inclusion; financial efficiency; capital misallocation; green innovation; GMM model

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1. Introduction

China's commitment to peak its carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 demonstrates its strategic commitment to green and low-carbon development and its responsibility as a major country in tackling climate change and building a community with a shared future for mankind. In order to achieve the two-carbon goal, China's economic development model needs to be transformed to a green and low-carbon process, as "peak carbon dioxide emissions" and "carbon neutrality" are also huge challenges for the Chinese government. Green technology innovation is one of the important methods to realize green sustainable development in China. In essence, green innovation is technological innovation that combines economic benefits and environmental protection. The attributes of quasi-public goods, high uncertainty and lack of funds all inhibit the motivation of enterprises to carry out green innovation to some extent, leading to the limited development of green production and green consumption. The rapid development of digital financial inclusion provides a new way to solve the financing dilemma of enterprise green innovation. Therefore, it is of great academic value and practical significance to study the relationship between digital financial inclusion and green innovation.

Inclusive finance refers to providing appropriate and effective financial services for all sectors of society with financial needs at affordable costs based on the requirements of equal opportunities and the principle of business sustainability, by increasing policy guidance and support, strengthening the construction of the financial system, and improving financial infrastructure. China's White Paper on the Development of Digital Inclusive Finance (2019) defines digital inclusive finance as providing equal, effective, comprehensive and

convenient financial products and services to all sectors of society, especially urban low-income groups, special groups of rural population, and small and micro enterprises that are not covered by the existing financial system, by means of various digital technologies, on the premise of controllable and sustainable costs. Rennings (2000) [1] gives a representative definition of green innovation, that is, green innovation is "new ideas, new products, new services, new processes or new management systems to deal with environmental problems". Green innovation is the creation of new and competitive goods, processes, systems, services and procedures that minimize the use of natural resources per unit output and the release of toxic substances while meeting human consumption needs.

Numerous studies have confirmed the positive impact of green innovation on economic development [2,3]. Green innovation is an important way to solve environmental pollution and improve the quality of economic development. Green innovation can reduce resources consumed in the process of economic development, reduce environmental costs and improve green total factor productivity [4–7]. Brunnermeier and Cohen (2003) [8] found that the higher a corporation's investment in environmental management costs, the more green patents the corporation has. Li et al. (2017) [9] found that corporate profits can positively promote green product innovation; in other words, enterprises with stronger profitability have more green product innovation. Wang et al. (2021) [10] suggested that green innovation can improve energy efficiency and promote energy structure upgrading. Zhao et al. (2022) [11] found that green innovation is conducive to improving green total factor productivity based on Chinese city-level data. However, the difficulty in financing green innovation projects is a major obstacle in green innovation, which is a practical problem that must be solved urgently in China. In recent years, digital financial inclusion has been promoted along with the vigorous development of artificial intelligence, big data, cloud computing and other digital technologies, providing new opportunities for enterprises to solve the financing dilemma of green innovation. Digital financial inclusion can effectively alleviate the financing constraint dilemma suffered by enterprises and provide stable financial support for corporate innovation [12]. Sun and Tang (2022) [13] found that digital financial inclusion can significantly promote sustainable economic growth and green innovation by increasing financial institution lending, household savings and consumption. Gao et al. (2022) [14] found that the development of digital financial inclusion is conducive to increasing green total factor productivity in agriculture based on panel data for 30 provinces in China from 2011 to 2019. Kong et al. (2022) [15] found that digital financial inclusion can promote green innovation by improving the degree of corporate environmental information disclosure and financing constraints of environmental enterprises. Liu et al. (2022) [16] found that digital finance promotes green innovation by easing corporate financing constraints and increasing R&D investment. Rao et al. (2022) [17] found that digital finance can significantly promote the quality and quantity of corporate green innovation. However, no literature has investigated the impact and internal mechanisms of digital financial inclusion on green innovation from the perspective of financial efficiency and capital misallocation.

Our contributions are twofold. First, by constructing a theoretical analysis framework, the relationship between digital financial inclusion and green innovation is studied from the perspective of financial efficiency and capital misallocation, which can provide a theoretical basis for digital financial inclusion to better serve corporate green innovation. Second, this research empirically examines the impact of digital financial inclusion on green innovation and its mechanisms based on dynamic panel regression models and mediation effect models. In this paper, the use of a dynamic panel is mainly based on the following two aspects. On the one hand, the lag effect leads to the previous level of green innovation affecting the current green innovation, and the dynamic panel regression model can control the adverse effects caused by the lag effect. On the other hand, there exists reverse causality between digital financial inclusion and green innovation. The dynamic panel regression method can reduce the bias caused by endogenous problems on regression results, to

enhance the robustness of regression results. The conclusion of this research can provide a realistic basis for solving the dilemma of corporate green innovation financing.

2. Theoretical Framework and Research Hypothesis

The impact of digital inclusive finance on green innovation is manifested in both direct effects and mechanism effects. The mechanism effects affect green innovation mainly through capital mismatch and financial efficiency.

2.1. The Direct Impact of Digital Financial Inclusion on Green Innovation

The development of digital financial inclusion based on new technologies such as big data, cloud computing and artificial intelligence can broaden the information access channels of financing providers and improve the information screening ability of financial institutions, thus reducing information asymmetry between financing providers and green innovative enterprises, which is beneficial in improving the level of green innovation [17]. From the perspective of cost–benefits, whether enterprises carry out green innovation usually depends on the financing cost of green innovation capital. Digital financial inclusion, which is gradually developed with the help of digital technology, can significantly reduce information asymmetry and transaction costs, thus improving the availability and convenience of financial services, so as to alleviate the financing constraints suffered by enterprises in the process of green innovation [15]. On the one hand, digital financial inclusion can more effectively pool small but large amounts of idle funds to provide more capital support for enterprises to carry out green innovation [18]. Therefore, digital financial inclusion not only improves the financing efficiency and availability, but also helps reduce the risks of green innovation of enterprises, which will increase the willingness of enterprise management to support green innovation of enterprises. On the other hand, digital financial inclusion is conducive to increasing residents' income, thus increasing social demand for and expenditure on green products, and ultimately encouraging enterprises to carry out green innovation [19]. Therefore, based on the above theoretical analysis, this study proposes hypothesis H1:

H1: Digital financial inclusion is conducive to promoting green innovation.

2.2. The Mechanism of Digital Financial Inclusion on Green Innovation

2.2.1. Mediation Mechanism of Financial Efficiency

Higher financial efficiency means that financial institutions are more efficient in allocating funds to enterprises' green innovation, thus meeting their financial needs for green innovation and technological upgrading [20]. Enterprise green innovation needs long-term sustained capital investment, which is one of the key factors for the success of enterprise green innovation. Digital financial inclusion is conducive to improving financial efficiency, thus enhancing the level of green innovation of enterprises. On the one hand, digital inclusive finance will adjust the supply level and allocation structure of financial resources through a resource allocation effect, broaden the financing channels of enterprises and enhance the liquidity of financial resources, thus shortening the capital turnover time. Digital financial inclusion can effectively reduce the financing cost of enterprises and shorten the waiting time for transactions, which will directly alleviate the financing constraints suffered by enterprises in the process of green innovation [16]. Furthermore, higher financial efficiency means better integration between the financial sector and enterprises, which will not only reduce the external financing constraints suffered by enterprises, but also improve the efficiency of enterprises in using financial resources, thus promoting enterprises to carry out green technological innovation. On the other hand, digital financial inclusion can provide more capital support for enterprises to carry out green innovation by improving the efficiency of financial services, including efficient savings–investment conversion and optimal allocation of financial resources. Higher efficiency of financial services means higher liquidity and allocation efficiency of financial resources, thus improving the level of

green innovation. Therefore, based on the above theoretical analysis, this study proposes hypothesis H2:

H2: Digital financial inclusion can promote green innovation by improving financial efficiency.

2.2.2. Mediation Mechanism of Capital Misallocation

Digital financial inclusion can help reduce transaction costs and improve the efficiency of credit transactions to mitigate capital misallocation [20]. There is serious information asymmetry in the traditional financial service system, which will intensify the misallocation of market resources and inhibit the green innovation activities of enterprises [21]. The most distinctive feature of digital financial inclusion is that it changes the traditional financial service mode, reduces the transaction cost of credit business, and makes the credit process between enterprises and financial institutions more transparent, thus enhancing the matching degree between capital supply and demand sides and reducing the degree of capital misallocation. On the one hand, digital financial inclusion, relying on digital technology, effectively alleviates the problem of information asymmetry within and across industries, accelerates the flow of capital resources among enterprises, reduces the flow cost, and thus helps to improve the efficiency of resource allocation [22]. On the other hand, the development of digital inclusive finance improves the matching efficiency between capital, land and other traditional factors, making resource allocation more efficient, which alleviates the inhibiting effect of capital mismatching on green innovation to some extent. Therefore, based on the above theoretical analysis, this study proposes hypothesis H3:

H3: Digital financial inclusion can promote green innovation by alleviating capital misallocation.

3. Research Design

3.1. Variables

3.1.1. Explained Variable: Green Innovation

Based on the practice of [15], this study uses the number of green invention patents as the explained variable to measure the green innovation level of each province. Patents are a creative solution with certain novelty, innovation and practicality. Novelty, creativity and practicality, respectively, indicate the non-repeatability of technical solutions, the significance of technological progress, and the high applicability of enterprise production processes.

3.1.2. Explanatory Variable: Digital Financial Inclusion

This research uses the Digital Financial Inclusion Index to represent the development of digital financial inclusion in China. Published in 2011, the annual Digital Financial Inclusion Index is co-compiled by Peking University's Research Center for Digital Finance and Ant Financial Services Group. Based on provincial data from 2011–2020, this study uses the logarithm of the Digital Financial Inclusion Index (*digf*) as the core explanatory variable. Taking the logarithm of digital inclusion finance can reduce the fluctuation of variable values and adverse impacts of heteroscedasticity on regression results. The digital financial inclusion index can be further divided into three dimensions: breadth of digital financial inclusion coverage (*digfg*), depth of digital financial inclusion use (*digfs*) and degree of digitalization of financial inclusion (*digfd*).

3.1.3. Mechanism Variables

(1) Financial Efficiency

In accordance with the principle of scientificity, foresight and operability, this study adopts the multi-input and multi-output DEA model to measure the financial efficiency (*ef*) of each province during 2011–2020 [20]. The specific indicators are shown in Table 1. On the one hand, this study intends to construct input indicators from two aspects: labor factor

input and capital factor input. Considering the uneven level of economic and financial development of each province in China, labor factor input is measured by the proportion of the number of employees in the financial sector to the total number of employees, while capital factor input is measured by the amount of fixed assets invested in the financial sector in each province. In order to eliminate the impact of excessive total GDP on the estimation accuracy, this study uses GDP per capita instead of GDP as an output indicator.

Table 1. Evaluation indicators of financial efficiency.

Variable	Type	Evaluation Indicators
Financial Efficiency	Input	Year-end deposit balance The proportion of employees in the financial industry to the total employed population Investment in fixed assets in financial industry Year-end loan balance
	Output	GDP per capita Year-end deposit balance

(2) Capital Misallocation

Based on [20,21,23], we divide production factors into capital and labor. Assuming the production function of enterprises in each province meets the Cobb–Douglas production function (C-D function), we apply Lagrange method to calculate the relative distortion coefficient of capital and labor under the profit maximization, and the specific settings are as follows:

$$\theta_{K_i} = \frac{K_i / \sum K_i}{s_i \alpha_i / \alpha} \tag{1}$$

$$\theta_{L_i} = \frac{L_i / \sum L_i}{s_i \beta_i / \beta} \tag{2}$$

where i denotes province; θ_{K_i} and θ_{L_i} denote the relative distortion coefficients of capital and labor, respectively; K_i and L_i are the capital stock and labor force in province i respectively; S_i denotes the ratio of GDP of province i to national GDP; α denotes the national capital elasticity, which is the share of capital factors invested in the production process; β denotes the national labor elasticity, which is the share of labor factors invested in the production process of the enterprise, and $\alpha + \beta = 1$; α and β represent the elasticity of capital and labor output in province i, respectively. The elastic coefficient values of α, β, α_i and β_i are estimated by the variable coefficient model based on the logarithm of the C-D production function.

Classical economic theory holds that capital and labor elements cannot be completely substituted for each other, so the relative distortion degree of capital and labor should be considered comprehensively to accurately measure capital mismatch. Therefore, according to [24], this study constructs the distortion degree of capital elements relative to labor elements to measure the capital misallocation. Specifically, this is as follows:

$$\hat{\theta} = \frac{\theta_{K_i}}{\theta_{L_i}} \tag{3}$$

As there are both over-allocation and under-allocation in capital misallocation, further calculations are as follows:

$$\theta = \hat{\theta} - 1 \tag{4}$$

where θ indicates capital misallocation. $\theta > 0$, $\theta = 0$ and $\theta < 0$ indicate over-allocated, not distorted and under-allocated capital factors relative to the labor factor, respectively. Therefore, considering the possibility of negative values of capital misallocation and avoiding the variation caused by positive and negative values to affect the regression results, this study further takes the absolute value of the coefficient of capital misallocation. The larger

the absolute value, the greater the degree of capital misallocation, that is, the more serious the misallocation of capital elements relative to labor (cmis) [20].

3.1.4. Control Variables

The control variables selected in this study are as follows: (1) Industry structure (*cy*), which is measured by the ratio of the added value of the tertiary industry to the added value of the secondary industry. The upgrading of the industry structure will increase the market demand for green technologies, which will help to achieve rational allocations of production factors and enable the coordinated development of various industries, thus enhancing the green innovation capacity of enterprises. (2) R&D investment (*lrd*), measured by the proportion of R&D investment in GDP of each province. The proportion of R&D investment in GDP can reflect the government's emphasis on innovation. The higher the proportion, the more attention the government attaches to innovation. (3) Human capital (*edu*), which is measured by the logarithm of the scale of college students in each province. Human capital is the basis for enterprises to carry out innovation activities. The more high-quality talents there are, the better it is for enterprises to take advantage of green innovation. Therefore, human capital is an important factor in green innovation. (4) The degree of technology marketization (*market*), which is measured by the proportion of the turnover of advanced technology to GDP in each province. Whether enterprises carry out green innovation activities depends on the benefits and costs of green innovation. Active technology market transactions will enhance the optimistic expectation of enterprise management on the economic benefits of green innovation.

Table 2 shows the descriptive statistics of the variables.

Table 2. Descriptive statistics.

Variable	Ods	Mean	Std	Min	Max
GI	300	6.3795	1.3385	1.9560	9.3546
digf	300	5.3824	1.1421	0.7655	6.8739
ef	300	0.7152	0.1309	0.3811	1.0000
cmis	300	0.7338	0.9532	0.0018	4.6385
market	300	0.0156	0.0271	0.0002	0.1758
lrd	300	14.3221	1.3526	10.9641	17.0344
cy	300	1.3246	0.7288	0.5272	5.2401
edu	300	4.2583	0.8003	1.5196	5.5284

3.2. Model

3.2.1. Baseline Regression Model

This study adopts a dynamic panel model to empirically test the research hypothesis H1. The first reason is that the change of green innovation usually has a lag effect, that is, the past green innovation will affect the current green innovation. Second, the dynamic panel regression model can reduce the estimation bias caused by the endogenous issues of digital financial inclusion and green innovation. It is worth noting that there are two types of dynamic panel models, differenced GMM and system GMM. Comparatively speaking, the system GMM can incorporate the difference equation and the level equation into the same framework for estimation, so as to effectively address the potential weak instrumental variable problem of the difference GMM. The dynamic panel model of system GMM constructed in this study is shown below:

$$GI_{it} = \eta_0 + \eta_1 GI_{it-1} + \eta_2 digf_{it} + \eta_j Control_{it} + \varepsilon_{it} \quad (5)$$

where *GI* denotes green innovation, GI_{t-1} denotes the lag of green innovation, *digf* denotes digital financial inclusion; *i* denotes province; *t* denotes year; η_0 denotes constant coefficient; η_1 denotes the coefficient value of digital inclusive finance, which is to reflect the degree of impact of digital inclusive finance on green innovation; *Control* denotes vector of control

variable coefficients; η_j denotes vector of control variable coefficients; ε_{it} denotes random error term.

The system GMM estimation method can be further divided into a one-step estimation method and two-step estimation method. Compared with the one-step estimation method, the two-step estimation method is based on the one-step estimation method by putting the variance obtained from the one-step regression into the regression, thus relaxing the assumption of independent and homoscedasticity in the one-step GMM, which can more effectively solve the endogeneity problem caused by the correlation between the variables and the error term. In addition, in order to ensure the validity of regression results, we conducted *AR* (2) statistic test and *Sargan* statistic test to test residual autocorrelation and instrumental variable over-identification, respectively.

3.2.2. Mediation Effects Model

In order to empirically test the mechanism of digital financial inclusion's influence on green innovation, this study constructs a mediation effect model. The specific equation is:

$$media_{it} = \beta_0 + \beta_1 media_{it-1} + \beta_2 digf_{it} + \beta_j Control_{it} + \varepsilon_{it} \quad (6)$$

$$GI_{it} = \alpha_0 + \alpha_1 GI_{it-1} + \alpha_2 digf_{it} + \alpha_3 media_{it} + \alpha_j Control_{it} + \varepsilon_{it} \quad (7)$$

where *media* denotes the mediation variables, which are financial efficiency and capital misallocation, respectively. If the coefficient value η_1 in the regression result of the baseline regression model (5) is significant at the confidence level, it indicates that there is a mediation effect and the test continues. Next, regression analysis using Equations (6) and (7), if β_2, α_2 and α_3 are significant at the confidence level, which indicates that the mediation effect of financial efficiency and capital misallocation is significant, which means that digital financial inclusion can have an impact on green innovation by influencing financial efficiency and capital misallocation.

3.3. Data Sources

In this paper, panel data from 2011 to 2020 of 30 provinces in mainland China, excluding Tibet due to lack of data, are used as the research object. The digital financial inclusion index is obtained from Research Center for Digital Finance at Peking University. Data on green invention patents and control variables were obtained from China Statistical Yearbook and National Bureau of Statistics of China.

4. Analysis of The Empirical Results

4.1. Analysis of Baseline Regression Results

4.1.1. Digital Financial Inclusion and Green Innovation

The results of the baseline regression model are given in Table 3. The results of AR (2) statistic test and Sargan statistic test show that there is no over-identification of instrumental variables and second-order autocorrelation of regression residuals, indicating that the regression results in Table 3 are valid. According to the benchmark regression results in column (1) in Table 3, the coefficient of digital financial inclusion is 0.0513, which is significant at the 5% confidence level, indicating that digital financial inclusion has a significant positive impact on green innovation, and improving the development level of digital financial inclusion is conducive to promoting green innovation. Therefore, the research hypothesis H1 is verified.

Table 3. Baseline regression results.

Variable	(1)	(2)	(3)	(4)
$digf_{t-1}$	0.4572 *** (13.56)			
$digfg_{t-1}$		0.4891 *** (18.30)		
$digfs_{t-1}$			0.2764 *** (5.87)	
$digfd_{t-1}$				0.4902 *** (17.17)
digf	0.0513 ** (2.33)			
digfg		−0.0654 * (−1.74)		
digfs			0.2818 *** (6.80)	
digfd				0.1674 *** (10.56)
market	1.5795 ** (1.97)	0.7524 (1.10)	2.7957 *** (4.66)	1.9796 *** (3.60)
lrd	0.3118 *** (9.70)	0.3216 *** (11.17)	0.2776 *** (4.66)	0.2721 *** (8.57)
cy	0.5303 *** (12.47)	0.5427 *** (11.00)	0.3495 *** (8.04)	0.3984 *** (9.76)
edu	0.3405 *** (8.21)	0.3284 *** (8.55)	0.5548 *** (8.99)	0.3026 *** (8.16)
cons	−3.4991 *** (−10.51)	−3.1518 *** (−13.51)	−3.8396 *** (−7.70)	−3.4896 *** (−13.47)
AR(2)	0.4218	0.3583	0.1739	0.4327
Sargan	0.2916	0.3091	0.3329	0.2883
Ods	300	300	300	300

Notes: (1) Values in brackets denote *T* values; (2) ***, ** and * denote significance at the 1%, 5% and 10% confidence levels respectively.

The results of columns (2), (3) and (4) in Table 3 use the breadth of digital financial inclusion coverage (*digfg)*, the depth of digital inclusive finance use (*digfs*) and the digitization degree of digital financial inclusion (*digfd*) as explanatory variables, respectively. The results show that the depth of digital inclusive finance usage (*digfs*) and the degree of digitalization of inclusive finance (*digfd*) have significant positive impact on green innovation at the confidence level of 1%, indicating that increasing the depth and degree of digitalization of digital inclusive finance is conducive to promoting green innovation. According to column (2) in Table 3, digital financial inclusion coverage breadth (*digfg*) has a significant negative impact on green innovation at the significance level of 10%. This may be due to the fact that the current digital financial inclusion coverage in China is still inadequate, and especially the support for green innovation of SMEs needs to be further strengthened. According to the regression results of different dimensions of digital financial inclusion, it can be seen that the promotion effect of digital financial inclusion on green innovation is mainly driven by the depth of digital financial inclusion use and digitalization, and the construction of the breadth of digital financial inclusion coverage still needs to be improved.

4.1.2. Robustness Test

The results of the robustness tests are presented in Table 4. In order to ensure the robustness of the regression results on the impact of digital inclusive finance on green innovation, this study adopts the following approach to conduct robustness tests. First, two control variables, per capita GDP and the proportion of fiscal expenditure in GDP, were added into the regression model, and the results are reported in column (1) of Table 4. The results show that the coefficient of the digital financial inclusion is still significantly positive at the confidence level of 5%. Second, we changed the measurement of green innovation, using the number of green invention patent applications in each province to measure green innovation. The regression results are shown in column (2) of Table 4. Compared with the baseline regression results in column (1) of Table 3, the coefficient values and significance of digital financial inclusion do not change significantly, which again proves the robustness of the regression results.

Table 4. Robustness tests.

Variable	(1)	(2)	(3)
digf	0.0574 **	0.0618 ***	0.1047 **
	(2.37)	(7.39)	(2.18)
Cons	−1.5654 ***	1.5231 **	−1.8533 ***
	(−5.72)	(2.20)	(−7.46)
Control Variables	Yes	Yes	Yes
AR(2)	0.1633	0.7437	0.2038
Sargan	0.4014	0.4716	0.2921
Ods	300	300	300

Note: (1) Values in brackets denote *t*-values; (2) ***, ** denote significance at the 1%, 5% and 10% confidence levels respectively.

Finally, we changed the estimation method by employing the differential GMM two-step estimation method for regression. The results obtained are shown in Column (3) in Table 4. The coefficient of digital financial inclusion remains significantly positive at the 5% confidence level, still indicating the robustness of digital financial inclusion to promote green innovation.

4.2. Mediation Effects Regression Results

4.2.1. Financial Efficiency Mechanism Effect

The regression results of the mediation effect of financial efficiency are presented in Table 5. As can be seen from column (1) in Table 5, digital financial inclusion has a significant positive effect on financial efficiency at the 5% confidence level, indicating that increasing the level of digital financial inclusion development is conducive to improving financial efficiency. Column (2) in Table 5 is the regression result of using the number of green invention patents obtained as the explained variable, while column (3) is the regression result of using the number of green invention patent applications as the explained variable. As shown in columns (2) and (3), the effects of digital financial inclusion on green innovation are significantly positive at the 5% confidence level, and the effects of financial efficiency on green innovation are significantly positive at the 1% confidence level, indicating that digital financial inclusion can promote green innovation by improving financial efficiency. That is, there is an action mechanism of "development of digital inclusive finance—improving financial efficiency—enhancing green innovation level". Digital inclusive finance can expand the scope of financial services, effectively reducing the reliance on outlets in the service process of financial institutions, with stronger geographical penetration and low-cost advantages. Meanwhile, it can provide financial services to corporations in a wide range of regions, and more financial resources can flow to the real economy sector, thus alleviating the financing constraints suffered by enterprises in the process of green innovation and improving their green innovation level. Therefore, the research hypothesis H2 is validated.

Table 5. Financial efficiency mediation effects regression results.

Variable	(1)	(2)	(3)
digf	0.0269 ** (2.36)	0.0487 ** (2.16)	0.0913 ** (2.25)
ef		1.6339 *** (8.19)	1.6145 *** (2.69)
Cons	−0.5164 *** (−3.51)	−0.1283 *** (2.83)	0.2497 *** (3.11)
Control Variables	Yes	Yes	Yes
AR(2)	0.5513	0.2385	0.1344
Sargan	0.5468	0.1164	0.4370
Ods	300	300	300

Note: (1) Values in brackets denote t-values; (2) ***, ** denote significance at the 1%, 5% and 10% confidence levels, respectively.

4.2.2. Capital Misallocation Mechanism Effect

The regression results of the mediation effect of capital misallocation are reported in Table 6. As can be seen from column (1) in Table 6, digital financial inclusion has a significant negative effect on capital mismatch at the 1% confidence level, indicating that increasing the level of digital financial inclusion development is helpful to mitigating capital misallocation. Column (2) in Table 6 is the regression result of using the number of green invention patents obtained as the explained variable, while column (3) is the regression result of using the number of green invention patent applications as the explained variable. As shown in the results in columns (2) and (3), the impact of digital inclusive finance on green innovation is significantly positive at the 5% confidence level. From columns (2) and (3) in Table 6, the coefficients of capital misallocation in the two models are significantly negative at the confidence level of 1% and 5%, respectively, indicating that the deepening of capital mismatch will inhibit green innovation. The above analysis shows that there is a mechanism of "digital financial inclusion development—alleviating capital misallocation—enhancing green innovation". Capital mismatch will lead to the fact that the capital collected by financial institutions in the form of savings cannot be efficiently transferred to real economy enterprises, which is not conducive to the business development and technological innovation of real economy enterprises, thus inhibiting green innovation. At the same time, capital mismatch will have negative externalities on the production and consumption of green products, leading to adverse selection and moral hazard, which will have a negative impact on the green innovation of enterprises. Digital inclusive finance can improve the efficiency of capital allocation and correct capital mismatch, so as to release the green innovation vitality and enhance the green innovation ability of enterprises.

Therefore, the research hypothesis H3 is validated.

Table 6. Capital misallocation mediation effects regression results.

Variable	(1)	(2)	(3)
digf	−0.1278 *** (5.59)	0.0746 ** (2.32)	0.0867 ** (2.38)
cmis		−0.3095 *** (−3.41)	−0.2813 ** (2.55)
Cons	−0.4558 ** (−2.13)	−0.2326 (0.87)	0.7735 (1.22)
Control Variables	Yes	Yes	Yes

Table 6. *Cont.*

Variable	(1)	(2)	(3)
AR(2)	0.1736	0.4298	0.1594
Sargan	0.6493	0.5640	0.1608
Ods	300	300	300

Note: (1) Values in brackets denote t-values; (2) ***, ** denote significance at the 1%, 5% and 10% confidence levels, respectively.

5. Conclusions

The study constructs a theoretical analysis framework from the perspective of financial efficiency and capital misallocation, and uses the dynamic panel system GMM model and the mediation effects model to empirically test the influence and mechanism of digital inclusive finance on green innovation according to the panel data of 30 provinces and cities in China from 2011 to 2020. Our key findings are as follows. First, digital financial inclusion has a significant positive impact on green innovation, that is, improving the development level of digital financial inclusion is conducive to promoting green innovation. Second, the mediation effect of financial efficiency is significant, and digital financial inclusion can promote green innovation by improving financial efficiency, which means that there is a mechanism of "digital financial inclusion development—improving financial efficiency—increasing the level of green innovation". Finally, the mediation effect of capital misallocation is significant, and digital financial inclusion can promote green innovation by alleviating capital misallocation, which means that there is a mechanism of "digital inclusive financial development→alleviating capital misallocation→ enhancing the level of green innovation".

Based on the above conclusion, this study proposes the following policy recommendations: On the one hand, it is necessary to promote the deep integration of digital inclusive finance and corporate green innovation business in order to improve the efficiency of financial services. By making full use of big data, cloud computing, artificial intelligence and other technologies, digital inclusive finance can effectively reduce the degree of information asymmetry between financial institutions and enterprises and improve the transparency of capital utilization, thus alleviating the financing constraints of enterprise green innovation. On the other hand, the government should improve the digital financial system and build a healthy application ecology of digital finance. Local digital finance-related regulations should be strengthened to provide space for the efficient use of digital finance and to support enterprises in developing more application scenarios that integrate digital finance and green innovation, so as to promote enterprises to improve green innovation. At the same time, regional differentiation in the use of digital inclusive finance should be actively explored, and digital finance should be applied in a targeted manner to support corporate green innovation according to the level of financial development, economic development and industry structure characteristics of different regions.

This paper can be extended and explored from different aspects. For example, the mechanism effect of digital inclusive finance on green innovation can be explored at the micro-firm level, and the heterogeneity that exists in the impact of digital inclusive finance on green innovation in different industries and different types of firms can be explored. Subsequent research can build a digital technology indicator based on text analysis to explore the impact of digital technology on enterprise green innovation, as well as the heterogeneous impact of different digital technologies such as big data technology, blockchain and artificial intelligence on green innovation. Finally, subsequent research could also analyze how digital inclusive finance influences green innovation behaviors through corporate behavioral decisions by constructing a theoretical model.

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