

# ***Digital Finance, Research and Development Investment, and Corporate Green Technology Innovation***

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**Abstract:** The development of digital finance is anticipated to alleviate the dilemma of corporate green technology innovation. This study selects manufacturing enterprises that are publicly listed on the Shanghai and Shenzhen stock exchanges as well as the Growth Enterprise Market in China, as research samples, of which the data spans from 2011 to 2020. An empirical research using a matched dataset of this period demonstrates that the growth of digital finance has a significantly positive impact on the promotion of green technology innovation in Chinese manufacturing companies. This result remains valid even after conducting rigorous testing to ensure its reliability and taking into account the potential influence of endogeneity. Moreover, this promoting effect exhibits heterogeneity due to differences in enterprise size and property rights. In the future, governments, financial institutions, and enterprises should collaborate to promote the improvement of digital finance infrastructure, bolster policies and financial support for enterprise green technology research and development (R&D) investment, and effectively foster the improvement of corporate green technology innovation capabilities.

**Keywords:** digital finance, corporate green technology innovation, research and development investment, mediating effect

## **1. Introduction**

China's economic development has garnered global attention since the implementation of the reform and opening-up. However, the development model characterized by significant pollution and high energy consumption exerts enormous pressure on resources and the environment, posing a serious threat to sustainable development. Currently, green development has become a key national strategy, and the impact of digital finance development on enterprise green innovation has also become an important issue. Researchers discovered that the development of digital finance is positively correlated with enterprise green innovation (EGI), and this association is particularly notable among enterprises located in the eastern region [1]. Li conducted a study using listed new energy companies as research samples and empirically tested the promoting effect of the development on innovation. Influenced by regional economy and policies, its promoting effect exhibits heterogeneity [2]. A scholar confirmed that online finance can promote EGI by reducing corporate leverage levels and increasing the involvement of non-controlling shareholders in decision-making [3]. Feng found that e-finance can effectively alleviate company financing constraints, reduce enterprise risks, and stimulate its green innovation [4]. However, cutting-edge financial theory and risk theory indicate

that Fin-tech, being a typical innovative finance, may lead to significant risks, potentially damaging activities such as environmental friendly technology transformation [5].

This study aims to explore, through literature review and analysis methods, whether fin-tech can effectively solve the dilemma of EGI, and whether it can enhance such innovation, as well as explore the way to convey the inherent mechanism of sustainable fin-tech revolution. By comprehensive review of former researches, it has been determined that there is a scarcity of studies examining the relationship between digital finance and EGI. The level of digital finance advancement plays a crucial role in influencing the innovation of green technology in companies, and has a basic impact on the input and output of enterprise environmentally friendly research and development (R&D).

## **2. Theoretical Analysis and Hypotheses**

### **2.1. Digital Finance and Green Technology Innovation**

The concept of technological innovation first appeared in Joseph Schumpeter's *The Theory of Economic Development*, where he argued that conventional technological innovation contributes to the advancement of economic progress. Fussler and James contended that environment friendly innovation refers to new things or productions that achieve environmental and business value objectives [6]. Green innovation projects involve high risk and investment, and long payback periods, which requires enterprises to acquire substantial R&D investment and sophisticated financial service systems. Therefore, emerging financial products such as digital format have become crucial for breaking through these barriers. Digital economy is a low-cost, widely accessible, and sustainable inclusive model that can attract small amounts of funds extensively, thereby increasing the overall quantity of capital funds. The main reason for the difficulty in corporate financing lies in the information asymmetry between enterprises and investment institutions. Fin-tech utilizes cutting-edge technologies to gather and analyze data on EGI. Facilitated by digital and traditional finance, social capital can swiftly converge on green innovation projects with strong capabilities, high potential, and high value. This measure aims to curtail or even limit the allocation of resources to businesses that have a significant negative impact on the environment. As a result, it will consistently bolster financial backing for the innovation development [7]. Therefore, the study presents the following hypothesis:

Hypothesis 1: Advancements in digital finance can facilitate the development of eco-friendly technological innovations in enterprises.

### **2.2. The Influence of Digital Finance on EGI**

Investment in R&D is widely recognized as a crucial driver of economic growth and corporate value [8]. The widespread adoption of fin-tech has driven the advancement of internet-based credit, leading to reduced expenses associated with obtaining loans for businesses. It also offers a broader range of financing options, allowing enterprises to obtain additional funding for R&D. The technology helps to reduce financial limitations and encourages innovation in EGI, which is significantly influenced by the increase in R&D spending [9-10]. By allocating resources such as cash, talent, and expertise, companies can enhance their understanding of the external knowledge resources necessary for green technology creation. However, long-term investments in R&D can improve the ability of enterprises to innovate technologically, which allows them to better adapt to the constantly evolving technological landscape and expedite the development of environmentally friendly green technologies. As a result, companies are propelled towards more sustainable and eco-friendly directions. Therefore, the study presents the following hypothesis:

Hypothesis 2: R&D investment is enhanced by the growth of financial technology, which acts as a mediating factor between R&D investment and EGI.

### 3. Research Design

#### 3.1. Sample Selection and Data Sources

Manufacturing companies listed on the Growth Enterprise Market and the Shanghai and Shenzhen stock exchanges between 2011 and 2020 are utilized in this study. Companies designated as ST (Special Treatment), \*ST, financial entities, or those lacking essential financial data are omitted from the sample data. Moreover, based on the inception year of provincial-level digital finance index in China (2011), a panel data set from 2011 to 2020 is constructed through pairing.

The study focuses on enterprise green technological innovation (PAT) as the dependent variable. The enterprise green patent output is a more accurate reflection of the EGI capability within the organization, compared to the Green Innovation Input Index. Hence, this study considers the logarithm of the total of green invention patent applications +1, as the dependent variable to measure EGI. The green patent data for manufacturing enterprises is collected from the China National Research Data Sharing Platform (CNRDS).

The explanatory variable in this study is digital finance (DFI). The measurement methods include single and the comprehensive index methods. This study measures the extent of fin-tech advancement in every province by utilizing the Digital Inclusive Finance Index published by the PKU Digital Finance Research Center.

As for control variables, according to other researches, this study selects enterprise age (AGE), return on assets (ROA), leverage ratio (Lev), the shareholding ratio of the largest shareholder (TOP1), number of senior management personnel (Ngg), and Tobin's q value (Tobinq) as control variables [11]. Regarding the mediating variable, the extent of R&D investment (RD) will affect the vitality of enterprise green technology innovation, which will be measured by the R&D investment. The economic characteristic data of these listed companies are collected from the CSMAR database.

#### 3.2. Descriptive Statistics of Variables

Following a thorough screening process, this study collects a reliable sample size of 13,666 A-share listed enterprises spanning from 2011 to 2020. A descriptive statistical analysis is performed on the primary variables, and following is the findings. The mean value of the Digital Inclusive Finance Index is 260.51, with the lowest and highest values being 16.22 and 431.93, respectively, which suggests notable disparities in the progress of digital finance in various regions of China, displaying a divided nature. The mean value of EGI in Chinese manufacturing enterprises is 0.507, with a range of 0 to 7.062, which suggests that the level of green technology innovation is relatively low and varies significantly among different enterprises.

Table 1: Descriptive Statistics of Main Variables

Variables	N	Mean	Sd	Min	Max
PAT	13,666	0.507	0.931	0	7.062
DFI	13,666	260.510	99.100	16.220	431.930
RD	13,666	1.96E+08	7.14E+08	0	1.59E+10
ROA	13,666	0.051	0.956	-3.994	108.366
Lev	13,666	0.383	0.287	-0.195	13.397
TOP1	13,666	33.587	14.180	0	89.090
NGG	13,666	6.350	2.381	0	23
AGE	13,666	17.057	5.690	2	62
Tobinq	13,666	2.283	3.647	0	192.705

### 3.3. Construction of Econometric Models

Upon performing the Hausman test, the fixed effects model is better suitable this analysis. Thus, this investigation establishes the subsequent fundamental model:

$$PAT_{i,t} = \alpha + \beta DIF_{i,t} + \sum \varphi CV_{i,t} + \lambda_t + \lambda_i + \varepsilon_{i,t}$$

The control variable is denoted by CV in this formula. In order to account for province-specific features that change over time, this study used a two-way fixed effects model that controls for the variable “year-province.”  $\varepsilon$  represents the random error component of the model. If  $\beta$  is significantly positive, it elaborates that fin-tech has a significant promoting effect on EGI. Conversely, if the coefficient is significantly negative, it shows that fin-tech has a significant limiting influence on EGI.

To further explore the mechanisms and channels through which the development of digital finance affects the incentive for EGI, the mediating effect method is employed for identification and testing. The model is constructed as follows:

$$RD_{i,t} = \psi + \psi_1 DFI_{i,t} + \sum \varphi CV_{i,t} + \lambda_t + \lambda_i + \mu_{i,t}$$

$$PAT_{i,t} = \xi + \xi_1 RD_{i,t} + \xi_2 DFI_{i,t} + \sum \varphi CV_{i,t} + \lambda_t + \lambda_i + \theta_{i,t}$$

If  $\psi_1$  is significantly positive, digital finance will have a positive impact on R&D investment; meanwhile, if the significance of  $\xi_2$  is weaker than  $\beta$ , or if the coefficient of  $\xi_2$  is smaller than  $\beta$ , it suggests that R&D investment is a significant factor.

## 4. Empirical Results

### 4.1. Baseline Regression Analysis

Table 2 shows the baseline regression analysis results that supported hypothesis 1. In column (1), digital inclusive finance has a correlation of 0.0024 on EGI without other variables. Digital inclusive finance positively affects the innovative technology at the 1% level. After controlling other factors, digital inclusive finance has a 0.0022 coefficient on enterprise green technology innovation at the 1% level, according to column (2)s regression analysis. This suggests that digital finance is continuously increasing manufacturing organizations' green technology innovation competitiveness and green innovation levels. This helps organizations develop competitive advantages and achieve environmental sustainability, quality, and long-term growth goals, verifying hypothesis 1.

### 4.2. Mediation Analysis

This study uses a mediation effect model to determine if R&D investment mediates the EGI mechanism of digital inclusive financing, whose results are displayed in Table 2. The digital finance variable DFI coefficient in column (3) of Table 2 is 2.2e+06, which is statistically significant at 1% level, indicating that digital financing promotes EGI, notably R&D investment. In column (4), the coefficient of digital finance is 0.0016 after integrating R&D spending, which is statistically significant at 1% level, showing that R&D spending reduces digital finance coefficient. This analysis indicates that the impact of digital inclusive funding on green technology innovation is partially mediated by R&D investment. Therefore, hypothesis 2 is true.

Table 2: Baseline Regression and Mediation Effect Results

	(1) PAT	(2) PAT	(3) RD	(4) PAT
DFI	0.0024*** (0.0006)	0.0022*** (0.0006)	2.2e+06*** (4.8e+05)	0.0016** (0.0006)
AGE		-0.0025 (0.0024)	5.6e+06** (2.1e+06)	-0.0039* (0.0023)
LEV		0.0668*** (0.0189)	4.2e+07** (1.5e+07)	0.0549** (0.0185)
TOP1		0.0004 (0.0006)	1.8e+06*** (4.9e+05)	-0.0002 (0.0006)
NGG		0.0187*** (0.0026)	8.9e+06*** (2.1e+06)	0.0164*** (0.0026)
ROA		0.0039 (0.0051)	2.3e+06 (4.1e+06)	0.0033 (0.0050)
Tobin Q		-0.0008 (0.0016)	-1.7e+05 (1.2e+06)	-0.0008 (0.0015)
RD				0.0000*** (0.0000)
_cons	-0.1053 (0.0816)	-0.2093** (0.0907)	-3.8e+08*** (7.5e+07)	-0.1076 (0.0877)
N	13666	13666	13666	13666
R2	0.0371	0.0361	0.0805	0.0668

Standard errors in parentheses: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001

### 4.3. Robustness Test

This study replaces the dependent variable in order to assess the strength and reliability of the results. It analyzes the impact of digital inclusive financing on the number of green utility model patent applications. The new dependent variable, PAT2, represents the natural logarithm of the rise of green patent applications by one. The findings are displayed in Table 3.

The coefficient of digital finance on company green technology innovation stays positive, supporting the previous findings. This suggests this study's findings are robust and credible.

Table 3: Robustness Test

	(1) PAT2	(2) PAT2	(3) RD	(4) PAT2
DFI	0.0022** (0.0007)	0.0020** (0.0007)	2.2e+06*** (4.8e+05)	0.0014** (0.0007)
Controls	YES	YES	YES	YES
_cons	0.0223 (0.0992)	-0.0585 (0.1102)	-3.8e+08*** (7.5e+07)	0.0370 (0.1079)
N	13666	13666	13666	13666
R2	0.0344	0.0341	0.0805	0.0511

Standard errors in parentheses: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001

#### 4.4. Endogeneity Correction

##### 4.4.1. Instrumental Variable Method

This study utilizes the instrumental variable method to tackle the issue of endogeneity. The instrumental variable used to measure the internet penetration rate (INTER) in each province was obtained from the China Internet Development Status Statistical Report. The empirical results of the instrumental variable method are presented in Table 4.

The results suggest that in the initial test, the regression coefficient for the internet penetration rate is 4.6121, which is statistically significant at the 1% level. This indicates a strong positive association between the internet penetration rate and the advancement of fin-tech. In the second-stage test, the coefficient of DFI is 0.0014, statistically significant at the 1% level, indicating that even after accounting for endogeneity by including instrumental variables, the advancement of digital finance continues to have a significant positive impact on EGI.

Table 4: Endogeneity Correction - Instrumental Variable Method

	First stage DFI	Second Stage PAT
INTER	4.6121***	
DFI		0.0014***
AGE		-0.0074***
LEV		0.3286***
TOP1		-0.0001
NGG		0.0646***
ROA		0.2440**
Tobinq		-0.0108***
_cons		-0.4027***

##### 4.4.2. Considering Lagged Effects

The impact of digital finance development may exert long-term influences. This study introduces a one-period lag for the explanatory variable to further consider lagged effects and overcome endogeneity issues. The regression results are displayed in Table 5, demonstrating that online finance has a consistently favorable effect on enterprise green innovation, confirming the study's conclusions and establishes the dependability of the findings.

Table 5: Endogeneity Correction - Lagged Effects

	(1) PAT	(2) PAT	(3) RD	(4) PAT
DFI	0.0024*** (0.0006)	0.0022*** (0.0006)	2.2e+06*** (4.8e+05)	0.0016** (0.0006)
Controls	YES	YES	YES	YES
_cons	-0.1053 (0.0816)	-0.2093** (0.0907)	-3.8e+08*** (7.5e+07)	-0.1076 (0.0877)
N	13666	13666	13666	13666
R2	0.0371	0.0361	0.0805	0.0668

Standard errors in parentheses: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001



## 4.5. Heterogeneity Analysis

### 4.5.1. Firm Size Heterogeneity

This study examines the varying effects of digital finance on the development of EGI in different-sized companies. It examines how organizations of different sizes prioritize green development and how digital financing drives innovation. The findings are displayed in Table 6. After controlling for multiple conditions, the effect of fin-tech on small enterprises' EGI is 0.0016, significant at the 5% level. The coefficient for large enterprises is 0.0030, also statistically significant at the same level. These findings suggest that major firms are more affected by fin-tech development on EGI. Larger organizations have better manufacturing and operating methods, more financial resources, and R&D support. Therefore, digital finance promotes EGI more in large-scale companies than in small ones. Columns 4a and 4b show that R&D exerts some mediating digital financing's effect on EGI, and large firms exhibit this mediation effect evidently.

Table 6: Firm Size Heterogeneity Analysis

	(1a) PAT	(1b) PAT	(2a) PAT	(2b) PAT	(3a) RD	(3b) RD	(4a) PAT	(4b) PAT
DFI	0.0018** (0.0007)	0.0030** (0.0010)	0.0016** (0.0007)	0.0030** (0.0010)	1.3e+05*** (3.9e+04)	4.7e+06*** (1.0e+06)	0.0014* (0.0007)	0.0018* (0.0010)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
_cons	-0.0173 (0.0850)	-0.2271 (0.1431)	0.0402 (0.0935)	-0.5495*** (0.1630)	6.7e+06 (6.2e+06)	-9.3e+08*** (1.6e+08)	0.0223 (0.0927)	-0.3305** (0.1577)
N	7499	6167	7499	6167	7499	6167	7499	6167
R2	0.0108	0.0623	0.0102	0.0619	0.2726	0.1319	0.0194	0.1005

Standard errors in parentheses: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001

“a” represents small-scale enterprises, and “b” represents large-scale enterprises

### 4.5.2. Property Rights Heterogeneity

Table 7 illustrates how this study examines the effect of fin-tech on the development of EGI with varying property rights. After accounting for covariates, state-owned companies' EGI has a regression coefficient of 0.0058 for the impact of digital finance, which is significant at the 1% level. Nonetheless, there is no statistically significant correlation between digital finance and the creation of green technologies in non-state-owned businesses. These findings suggest that state-owned firms' adoption of green technology is more positively impacted by the growth of digital finance. State-owned businesses have always had an advantage in terms of resources and are quicker to adapt to environmental regulations. In comparison to non-state-owned businesses, they also make more significant investments in green technology R&D. In terms of the mediating effect, research and development spending is not as important in non-state-owned firms as it is in state-owned enterprises referring to the impact of digital finance on green technology innovation.

Table 7: Property Rights Heterogeneity Analysis

	(1a) PAT	(1b) PAT	(2a) PAT	(2b) PAT	(3a) RD	(3b) RD	(4a) PAT	(4b) PAT
DFI	0.0058*** (0.0011)	0.0013* (0.0007)	0.0058*** (0.0011)	0.0010 (0.0007)	8.3e+06*** (1.1e+06)	1.1e+04 (4.7e+05)	0.0040*** (0.0011)	0.0010 (0.0007)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
_cons	-0.2759* (0.1592)	-0.0348 (0.0978)	-0.4392** (0.2027)	-0.0282 (0.1062)	-5.8e+08** (2.0e+08)	-1.3e+08* (7.4e+07)	-0.3207* (0.1932)	0.0157 (0.1027)
N	3771	9895	3771	9895	3771	9895	3771	9895
R2	0.0701	0.0272	0.0713	0.0261	0.0983	0.0911	0.0993	0.0547

Standard errors in parentheses: \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.001

“a” represents state-owned enterprises, “b” represents non-state-owned enterprises

## 5. Conclusion

This study analyzes the yearly data of manufacturing companies listed on the A-share market in China from 2011 to 2020, establishing a panel regression model to investigate the impact of digital finance development on enterprise green technology innovation and its heterogeneity characteristics, and it explores the mediating effect of research and development investment. The use of digital finance has a substantial positive impact on the innovation of green technology within firms. This conclusion remains statistically significant even when other measurement indicators are used for the dependent variable, indicating the strength and reliability of the analysis. Furthermore, the investment in R&D acts as a mediator in the influence of digital finance development on the creation of environmentally friendly technology in enterprises. The impact of the growth of digital finance on the promotion of EGI shows noticeable variations. To effectively increase innovation in green technology within enterprises, it is imperative to prioritize the development of digital finance in the future. The government should augment investment in digital technology infrastructure to bolster the advancement of the digital finance system. Moreover, firms should enhance their investment in R&D specifically towards green technology innovation. Enterprises can create specific funds for R&D that are only focused on supporting innovative ideas in green technology within the digital banking industry. Organizations should enhance their R&D management systems in order to enhance the effectiveness of research and development and the speed at which research outcomes are translated into practical applications. This entails the establishment of a scientifically sound method for evaluating research and development projects, enhancing the system for protecting intellectual property, and bolstering the conversion and utilization of research and development outcomes. Given the substantial diversity in the effects of digital finance on the innovation of environmentally friendly technology in businesses, it is crucial for the government and financial institutions to enhance their assistance and development of small-scale enterprises. This can be achieved by offering increased financial and technical support through digital finance platforms, thereby expediting their progress in green technology innovation.

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