

## Research Article

# Does Digital Finance Induce Improved Financing for Green Technological Innovation in China?

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Received 2 January 2022; Accepted 2 February 2022; Published 16 March 2022

Academic Editor: Stefan Cristian Gherghina

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Sustained and stable external financing, affected by the financial environment, is a necessary condition to support the green technological innovation of enterprises. This paper focuses on the impact of bettering the financial environment of digital finance on enterprise green technological innovation, as well as the mediating role of financing costs and financial flexibility in this process. Using China's data on manufacturing enterprises listed in Shanghai and Shenzhen from 2011 to 2018, the hypotheses are tested. The result suggests the following: (a) digital finance effectively promotes enterprises to carry out green technological innovation, specifically, the coverage and depth of digital finance can promote enterprises' green technological innovation, but the degree of digitization has no significant impact; (b) digital finance improves the financial environment by making up the shortage of traditional financial system through reducing financing problems such as "financing difficulty," "matching difficulty," and "supervision difficulty," which make effective contributions to enterprise green technological innovation; (c) financing costs negatively mediate the relationship between digital finance and enterprise green technological innovation, while financial flexibility positively mediates the relationship. Overall, our findings shed light on the role digital finance plays in shaping corporate environmental behavior—and ultimately innovation in sustainability—in financing constraint setting.

## 1. Introduction

Achieving an innovation-driven economy and embarking on the path of green development has become a widely recognized goal of people around the world. Green technological innovation can not only create economic value by relying on the innovation effect but also improve the environmental value by improving production and reducing energy consumption [1]. It helps build an efficient, clean, low-carbon, and circular green manufacturing system, which is a necessary way to achieve long-term green development. Meanwhile, green technological innovation is an activity of high risk and high investment, which needs the support of a large amount of external financing. However, due to the problems such as the existing technological spillover effect, long investment return period, difficulty to quantify the investment value, and so on resulting in information asymmetry, most enterprises carrying out green

technological innovation are faced with financing difficulties [2]. In order to achieve long-term green development, the Chinese government began building a green financial system as early as more than ten years ago to help companies achieve green upgrades from the banking system, creditor market, and institutional investment. Although the measures have an active effect on energy consumption and pollutant emissions, there is no significant role in promoting corporate green technological innovation, and companies are still in the "innovative dilemma."

Technological innovation has an important impact on environmental quality, especially in developing economies [3]. Green technological innovation is one kind of technological innovation that is aimed at resource conservation and environmental protection [4]. For enterprises, developing green technology would be beneficial both to promote environmental performance through technological upgrading and process optimization and to promote long-

term financial performance by reducing environmental regulation costs. Therefore, a large proportion of literature studies have studied the internal and external factors that affect enterprises' green technological innovation.

According to Porter's Hypothesis, environmental regulation has a significant positive effect on corporate green technological innovation [5], which at the same has been confirmed by several studies [6–8]. However, the impact of environmental regulation on enterprises is realized through the external pressure, and it does not solve the unavoidable financial problems in enterprises' green technological innovation activities. According to the existing literature, convenient external financing is conducive to corporate R&D investment [9] and has a positive role in the process of technological innovation [10]. Yet, some literatures pointed out that financial obstacles caused by the inefficiency of the financial system can reduce the continuous R&D investment of enterprises and have a direct negative effect on the green technological innovation of manufacturing enterprises [2]. In the traditional financial system, commercial banks are the main source of external financial support for enterprises' innovation activities. Bank credit can provide green technological innovation funds for enterprises without deep pockets and improve their viability under current national environmental governance [11]. However, bank credit does not fully meet the external financing needs of corporate green technological innovation but also need to improve financial market tools to diversify R&D risks [12] and need the complementary role of corporate commercial credit [13], as well as government-subsidized funds to supplement [14], to reduce the insufficiency and instability of external financing and to maintain the continuous smooth of green technological innovation. Green financial policies are beneficial to improve the funding efficiency of the financial system to enterprise green technological innovation in China. Moreover, if financial institutions' investment in green technological innovation wants to be further improved, information disclosure needs to be resolved more effectively [15]. The existing literature studies show that the financing environment has an important impact on green technological innovation, while the financial system still has insufficient supply, low efficiency, and lagged information in financing support to enterprise green technological innovation. Therefore, how to enhance financial systems' positive effects of green technological innovation is worthy to be further studied.

As the same as technological innovation, financial innovation also has an important impact on environmental quality [16]. Digital finance is a vital financial innovation. Digital finance is booming with the progress of information technology, which makes use of technologies to transform service scenes and upgrade financing mode in various aspects. Block-chain technology reconstructs the trust mechanism of financing parties. Cloud computing technology promotes the connection between financial subjects. The development of digital finance is crucial to improving the efficiency of the financial system. First of all, digital finance combines finance with technology, which contributes to the accumulation of more leisure funds, increases the

supply of financial resources for innovation activities, and promotes enterprise innovation through precise risk pricing and intensive business processes [17]. Second, digital finance helps to improve the financial structure, forces the transformation and upgrading of the financial sector, and enhances the efficiency of financial resource allocation and risk management ability [18]. At the same time, the traditional credit pricing model should be changed, the boundary constraints of traditional finance should be broken, the financing threshold and financing costs should be lowered, and the financing constraints of innovative enterprises should be alleviated [19]. Third, Fin-tech can help strengthen enterprise information transparency, correct resource mismatch in the financial system, provide financing parties with lower costs and better service experience, and help enterprises innovate by avoiding adverse selection and moral hazard problems in the financial market [20]. The development of digital finance will change the supply of financial elements and will also significantly affect the company's innovation activities.

Although the research studies mentioned above have provided some references for exploring the influence of digital finance on corporate green technology, there are still the following shortcomings. First of all, the existing literatures mostly pay attention to the impact of financial development on the environment from a macroperspective, but there is still a lack of research on the impact of financial development on the green behavior of microenterprises. Moreover, existing studies have focused on the improvement of digital finance to the financial system, but there is still a lack of attention to the specific effect of such improvement on the environment and the effect of such improvement on enterprises' green behavior. Based on this, this paper attempts to study financial development and environmental improvement from the perspective of enterprises. The novelty of this work is as follows: First, this paper builds a comprehensive analysis framework integrating digital finance, financial environment, and enterprises' green technological innovation and focuses on the impact of digital finance and its various dimensions on enterprises' green technological innovation, enriching the relevant theoretical research of financial environmental impact on green development of enterprises. Second, this paper focuses on judging whether the development of digital finance can make up for the problems of structural distortion, resource mismatch, and inefficiency in the traditional financial system in the actual economic activities and broadening the research boundary of the impact of digital finance development on the financial system. Thirdly, taking into account the two intervening variables of financing costs and financial flexibility, the paper tries to further explore the mechanism black box between digital finance and enterprises' green technological innovation.

## 2. Theory and Hypothesis

*2.1. The Impact of Digital Finance on External Financial Environment.* Promoting companies' commitment to green technological innovation is an important path to realize

green development and the inevitable choice for enterprises to achieve environmental value and financial value. However, green technological innovation is a systematic activity with a long investment period and high investment risk, which requires the support of a large amount of external financing [21]. There is no denying that China's traditional financial system is still immature, with a series of problems such as few financial suppliers, distorted capital allocation, and preference for short-term speculation [22]. It still needs to move forward in the direction of eliminating financial deficiency and further serving the real economy. Digital financial development, on the basis of financial operation pattern transformation and upgrading from the science and technological strength, helps to improve the breadth and depth of financial services, effectively compensate for insufficient financial systems, optimize financial resource allocation, improve corporate financing environments, and then provide more resource support for corporate green technological innovation. Accordingly, digital financial development can improve corporate green technological innovation financial environment in the following ways.

First, the development of digital finance broadens capital sources and financing channels and reduces the problem of "financing difficulty" of enterprises. In the traditional financial system, the supply sources of financial resources are mainly large commercial banks, securities institutions, fund companies, etc. Under this situation, a large number of "loose funds," namely, retail funds that have not been gathered and effectively used, are omitted in the market. Digital finance relies on big data, cloud computing, block-chain, Internet technology, artificial intelligence, and other scientific and technological means to collect and process massive data, build multiple service scenarios, gather the long-tail groups in the financial market, efficiently absorb and utilize a large number of "loose capital," and enrich the sources of capital. In addition, the financial means and service scenarios added by digital finance provide enterprises with more diversified financing channels and methods [23]. Therefore, the development of digital finance can significantly expand the company's financing options and provide sufficient financial support for enterprise green technology research and development.

Second, digital finance can effectively reduce information search costs and transaction costs and relieve the persistent disease of "matching difficulty" of financial resources. China's financial system, which is dominated by indirect financing, leads to a serious shortage of financial resource allocation efficiency. In view of the widespread information asymmetry problem, financial institutions are faced with high search costs and supervision costs, and enterprises also have a high cost of information self-verification [24]. The financial system favors large enterprises with deep financial resources and mature projects with low risks while growing enterprises with short development funds and long-term development projects with high risks are trapped in financing difficulties [25]. The development of digital finance makes it possible to collect massive enterprise

data, standardize nonstandardized information data, and thereby perform depth analysis and excavation of it, which can significantly reduce the cost of search and transaction of financial institutions, and carry out a more comprehensive and accurate risk assessment on financing enterprises with lower cost and lower risk. In other words, the development of digital finance helps to avoid adverse selection in the financial market and reduce financing difficulties faced by green technological research and development.

Moreover, the development of digital finance strengthens the transparency of enterprise information and optimizes the dilemma of "supervision difficulty" of green technological innovation. The financing evaluation of traditional financial institutions focuses on the easily realizable assets of enterprises while neglecting the technological and innovation ability of enterprises, precisely because it is difficult to quantify the technology and innovation, the investment return period is long, and the development process is difficult to supervise [26]. The lack of information transparency makes it difficult for investors to trust enterprises, which also leads to the moral hazard problem of insufficient action of green technological development projects [27]. Digital financial technical support can accumulate credit data for enterprises and provide a credit basis for financing parties through comprehensive mining of enterprise information. At the same time, it can also improve the transparency and standardization of contract execution by signing smart contracts. Further, the credit system supported by big data and block-chain technological in digital finance can improve the internal and external information transparency of enterprises, supervise the behaviors of enterprises after the signing of contracts, shorten the time for enterprises to benefit from breach of contract, increase the cost of a breach of contract, and reduce the moral hazard behavior of "free rider" of enterprises. The establishment of such a continuous trust mechanism will help to change the attitude of financing parties in the long run, so that green technological innovation projects, which were originally unpopular, can get more financial support.

Based on the above analysis, hypotheses H1 and H2 are proposed in this paper.

Hypothesis H1: the development of digital finance has a significant positive impact on enterprise green technological innovation

Hypothesis H2a: the development of digital finance will lead to a stronger positive impact on green technological innovation of enterprises with poorer financing status by resolving the problem of "financing difficulty"

Hypothesis H2b: the development of digital finance will form a stronger positive impact on green technological innovation of enterprises with higher green innovation capacity by reducing the "matching difficulty" of financial resources

Hypothesis H2c: the development of digital finance will contribute to a stronger positive impact on green technological innovation of enterprises with weaker

information quality by reducing the “supervision difficulty” of green technological innovation

*2.2. The Impact of Digital Finance on Internal Financial Environment.* Adequate and stable internal capital is an important guarantee to smooth the R&D investment of enterprises [28] and keep the sustainable and long-term green technological innovation of enterprises. Digital finance can not only integrate resources and broaden financing channels to increase financing flexibility but also establish a trust mechanism to accelerate the completion of transactions and reduce transaction costs, which will benefit financing activities of enterprises from various aspects and help reduce financing costs of enterprises. The reduction of enterprise financing costs enables enterprises to have more funds available for deployment, which helps ensure the stable investment and continuous progress of green technological innovation activities of enterprises.

In addition, digital finance can help companies improve their financial resilience. Based on the decentralized technology of block-chain, digital finance records and stores the upstream and downstream enterprises’ data from all links of the industrial chain, establishes the identity identification and tracking data platform, and activates the assets such as warehouse receipt, inventory, and receivables, which originally have a long realization cycle, so that the operating assets of enterprises can also be converted into cash flow at low cost and high efficiency. Moreover, digital technology converts traditional bank bills into digital bills, improves the recognition of interbank bills, improves the liquidity of commercial bills and other important financing instruments, and reduces their discount costs [29]. More importantly, the multiscene application and multilink connection of digital technology can also help enterprises improve their ability of information processing and make better decisions in managing cash flow and investment and financing activities. The circulation and management of more flexible and efficient operating assets will certainly be conducive to the improvement of the financial situation of enterprises, that is, the increase of the flexibility of the financial elasticity of enterprises. All these will provide support for the company’s continued and stable green technological innovation activities by increasing and smoothing the funds available. Based on the above analysis, hypothesis H3 and hypothesis H4 are proposed in this paper.

Hypothesis H3: the development of digital finance promotes green technological innovation of enterprises by reducing the enterprises’ financing costs.

Hypothesis H4: the development of digital finance promotes green technological innovation of enterprises by improving their financial flexibility.

The research framework of this paper is shown in Figure 1.

### 3. Experimental

*3.1. Data and Samples.* Considering that manufacturing enterprises are the most important subjects of green

technological innovation, developing countries should pay more attention to the improvement of environmental quality [30, 31]. This paper takes Chinese manufacturing enterprises listed in Shanghai and Shenzhen as the research samples. The digital finance development data comes from the Digital Finance Inclusive Finance Index of Peking University, and the period of the digital finance index from 2011 to 2018 is taken as the time window of this paper. Green technological innovation data comes from the China Research Data Service Platform (CNRDS) and the State Intellectual Property Office’s official website. Data at the microlevel were obtained from the China Stock Market and Accounting Research Database (CSMAR). In this paper, the digital financial index is matched with the data of listed companies, and the unbalanced panel data is constructed. The selected samples are further screened according to the following order: (1) delete the ST and \*ST categories and delisted companies; (2) delete all listed companies with discontinuous or seriously missing important data; (3) delete asset-liability ratio greater than 1, namely, insolvent company; (4) delete companies that have fewer than three companies in an industry. After the above screening, a total of 7714 observed values were obtained. 1% tail reduction was adopted for all continuous variables in the data to eliminate the influence of extreme value.

*3.2. Measurement of Variables. Green Technological Innovation (Greeninno).* There exists a rich literature on green technological innovation from the industrial level to the enterprise level. Most researches use the energy consumption level in the production process, environmentally friendly research and development, and the green patent to measure green technological innovation. Considering the accuracy and data availability of variable measurement, this paper selects green patent applications of enterprise as the measuring variables [32, 33], and considering that the green invention patent technological content is higher, there is more representative substantial green technological innovation, so we choose the number of application for green patent for invention as indicators of green technological innovation. The specific measure is the number of invention patents add 1 and take the log, and the sum of the number of utility model patent applications is used as the robustness test.

*Digital Finance (DFINA).* Based on massive users’ data, the Internet Finance Research Center of Peking University and Ant Financial jointly compiled the Digital Finance Inclusive Financial Index, which covers the data of 31 provinces and 337 cities in the Chinese mainland, including digital finance index. It also measures the development of digital finance in each region from three aspects of digital finance breadth, depth, and degree of digitization [34]. The index is most frequently used in the research of digital finance. In this paper, the digital financial inclusion index at the city level is used as the explanatory variable of this study, and the index is normalized.

Considering the large heterogeneity of green new technological research among enterprises, in order to



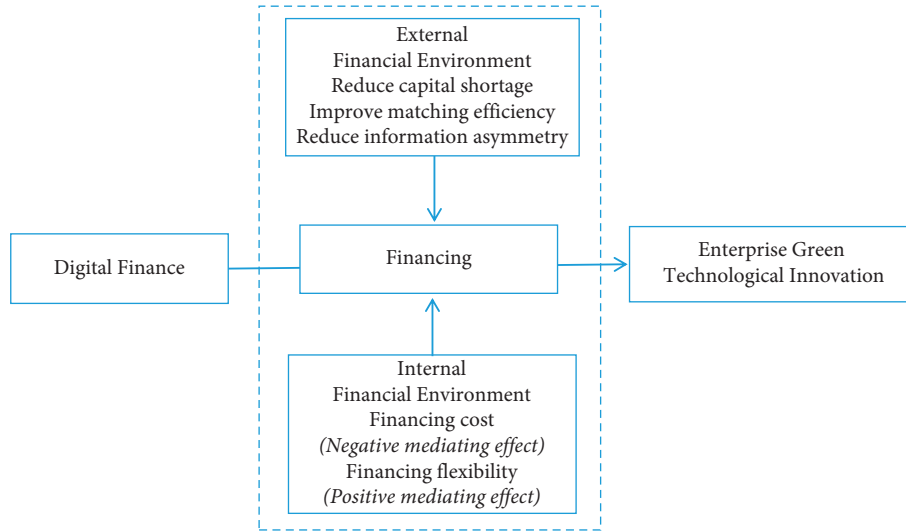


FIGURE 1: Research framework.

minimize the statistical impact caused by missing variables, this paper included enterprise variables as control variables from multiple aspects, specifically including (1) enterprise characteristics: enterprise age (age), enterprise size (size), and property rights (soe); (2) corporate governance: proportion of independent directors (outer) and degree of ownership concentration (no1); (3) financial situation: financial leverage (lever), current ratio (L-ratio); (4) corporate

competitiveness: Lerner index (Lerner) and growth rate of operating income (growth).

3.3. *Research Model.* This paper focuses on the impact of digital finance on green technological innovation. In order to test the relationship between the two, we build an econometric model:

$$\text{Greeninno}_{i,t} = \alpha_1 + \beta_1 \text{DFina}_{i,t-1} + \sum \gamma \text{Controls}_{i,t-1} + \sum \text{Ind} + \sum \text{Year} + \varepsilon \tag{1}$$

In the regression equation,  $\text{Greeninno}_{i,t}$  is the dependent variable green technological innovation,  $\text{DFina}_{i,t-1}$  represents the independent variable of the development degree of digital finance, and  $\text{Controls}_{i,t-1}$  is all the control variables mentioned above. In order to overcome the endogenous problems that may be caused by the omission of variables and reverse causality, this paper, drawing on the research method of Wooldridge [35], treated the explanatory variables and all the control variables with a delay of one period. At the same time, based on the bidirectional fixed-effect model, we adopt the clustering robust standard error in the regression test by controlling the industry effect and time effect.

## 4. Results and Discussion

4.1. *Descriptive Analysis.* Table 1 reports the basic statistical results of the variables. The minimum value of the digital finance index is 0.1628 and the maximum value is 0.9619, indicating that the development level of digital finance is relatively unbalanced. The maximum value of green invention patent data is 4.9127, while the mean value is only 1.2628, and the median value is only 1.0986, indicating that the number of green patents in most manufacturing enterprises in China is relatively small, and the progress of

green technological innovation activities is seriously insufficient. As can be seen from the results of financial leverage and liquidity ratio, there is a large gap in the financial situation of China's manufacturing enterprises, most of which have insufficient liquidity and are in a tight financial situation.

4.2. *Basic Empirical Results Analysis.* In Table 2, column one shows that the digital financial significantly positively affects the green technological innovation with statistically significant at the level of 1%, indicating that the development of digital financial level contributes to the improvement of the green technological innovation output of enterprises. With the development of digital finance, companies are facing a better financing environment, which makes enterprises have better green technological innovation performance. Therefore, H1 is supported.

Columns two to four in Table 2 report the impact of the digital financial segmentation dimension on green technological innovation. The coverage breadth and usage depth of the digital financial index have a positive effect on green technological innovation, which are statistically significant at the level of 1% and 5%, respectively. However, the digitization degree of inclusive finance has no statistically

TABLE 1: Descriptive statistical analysis of the main variables.

Variable	Variable definitions	Mean	Min.	Med.	Max.
DFINA	Digital finance index	0.6329	0.1628	0.6635	0.9619
Greeninno	Ln (number of invention patents +1)	1.2628	0.0000	1.0986	4.9127
Age	Ln ( number of years since the establishment of the enterprise )	2.8477	2.0794	2.8904	3.5553
Size	Ln ( Total assets )	12.9345	10.5801	12.7706	16.1704
Soe	Property right nature for state-owned enterprises take 1, otherwise take 0	0.3168	0.0000	0.0000	1.0000
Outer	Number of independent directors/number of boards	0.3765	0.0000	0.3571	0.8000
no1	The proportion of the largest shareholder of the company	0.3152	0.0300	0.2939	0.8824
Lever	Total liabilities/total assets	0.4044	0.0491	0.3997	0.8600
l-ratio	Current assets/current liabilities	2.6151	0.4409	1.7165	18.7324
Lerner	Lerner index of companies	0.0440	-0.2711	0.0251	0.4365
Growth	(Current operating income–previous operating income)/previous operating income	0.3735	-0.9069	0.2699	2.0421

TABLE 2: The basic regression results.

	(1) Greeninno	(2) Greeninno	(3) Greeninno	(4) Greeninno
L.Dfina	0.4740*** (3.187)			
L.Dfinabre		0.3584*** (2.643)		
L.Dfinadep			0.3327** (2.092)	
L.Dfinadigital				0.2543 (1.241)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Industry effect	Yes	Yes	Yes	Yes
_Cons	1.0398*** (6.154)	-3.0097*** (-8.780)	-2.9914*** (-8.740)	-2.9577*** (-8.663)
N	4961	4960	4960	4960
r2_a	0.0390	0.1191	0.1186	0.1181

*t* statistics in parentheses; \*  $p < 0.1$ , \*\*  $p < 0.05$ , and \*\*\*  $p < 0.01$ .

significant impact on the green technological innovation of enterprises. It shows that digital finance plays a positive role in promoting green technological innovation, and more attention should be paid to the extensive coverage of the development of digital finance in regions and the in-depth mining and application of various business scenarios, so as to promote the development of green technology of enterprises more effectively from these two dimensions.

**4.3. Analysis of the Complementary Role of Digital Finance in Financing.** As mentioned above, digital finance can make use of information technological advantages to effectively eliminate the “financing difficulty,” “matching difficulty,” and “supervision difficulty” caused by the inefficiency and high cost in the operation of the traditional financial system. Then, Does digital finance, integrated with the advantages of technology and model, make up for the lack of traditional finance in driving enterprise green technological research and development? In order to further explore the compensatory effect of digital finance on traditional finance and whether this effect can support green technological innovation, this paper examines the role of digital finance in the sample of different enterprises. In order to discuss whether to reduce “financing difficulty,” samples of enterprises with

different degrees of financing constraint and financial risk were investigated, respectively. In order to discuss whether to relieve “matching difficulty,” samples of enterprises with different degrees of industry concentration and different enterprise life cycles were investigated, respectively. In order to discuss whether to optimize “supervision difficulty,” the samples of enterprises with different quality levels of environmental disclosure reports and environmental governance reports were investigated.

**4.4. Does It Reduce “Financing Difficulty”?** According to the existing research, the higher the degree of financing constraints enterprises are faced with, the greater the financing dilemma; the higher the financial leverage of the same enterprise financial risk, the greater the burden, and the easier it is faced with financing difficulties, so this part chooses financing constraints and financial leverage as two indicators; according to the median of enterprise samples, they were divided into high financing constraint group and low financing constraints and the high and low financial risk groups. According to Hadlock and Pierce [36], the SA index is selected as the measurement index for financing constraints. The calculation formula is as follows:  $SA = -0.737size + 0.043size^2 - 0.04age$ . The calculation

formula of financial leverage is  $\text{financial leverage} = \frac{\text{total liabilities}}{\text{total assets}}$ .

Table 3 shows that the digital financial only has a significant positive impact on the green technological innovation of enterprises in the high financing constraint group and the high financial leverage group, and they remain significant at the 5% and 1% levels, respectively. The empirical results show that, in the case of financing constraints and financial dilemmas, the manufacturing enterprises with better development of urban digital finance can get more help to alleviate financing and financial difficulties and continue to develop green technological innovation activities. Digital finance has provided more capital sources and financing channels for green innovation projects, effectively alleviating the difficulties caused by capital problems to green innovation activities of enterprises, that is, helping enterprises with poorer financing status to reduce the “financing difficulty.” Therefore, hypothesis 2a is supported.

*4.5. Does It Reduce “Matching Difficulty”?* Enterprises with a high concentration of market structure have a higher market position and are more likely to obtain more financial resources in the traditional financial system resource allocation. However, a lower concentration of market structure with more market competition is more conducive to green technological innovation. Enterprises in the low market concentration industry have greater green technological innovation motivation, while enterprises in competitive intensity industries face greater capital constraints for green technological innovation [37] and have a higher demand for financial resources. Therefore, this part chooses the HHI index to measure market concentration. Enterprises below the quantile of 25% are divided into the sample of enterprises with low industry concentration, and enterprises above the quantile of 75% are divided into the sample of enterprises with high industry concentration, so as to investigate whether digital finance helps enterprises in industries with low concentration which are not helped enough by the traditional financial system.

The enterprise life cycle is also closely related to green technological innovation capacity. It is different from the green innovation willingness and access to financial resources of enterprises in different stages of development. Enterprises in the growth stage and mature stage are the main forces to carry out technological innovation [38]. Enterprises in the mature stage have more abundant self-owned funds and external sources of funds, while enterprises in the growth stage often face greater capital pressure due to insufficient market recognition. Financial resources are needed not only to help the right business but also to help it at the right time. Therefore, this part examines whether digital finance has supported green technological innovation at the right time by dividing enterprises into three types: growth, maturity, and decline. Drawing on the cash flow model method of Dickinson [39], we use the positive and negative combination of the net cash flows of three kinds of activities, namely, business activities, investment activities, and financing activities, to reflect the characteristics of

operating risk, profitability, and growth rate in different life cycles and divide enterprises into a growth period, maturity period, and decline period according to the different characteristics. This classification method can not only avoid subjective assumptions about the distribution of life cycle samples but also avoid the interference of inherent industry differences.

The results in Table 4 show that, according to the level of competition in the industry, digital finance only has a significant positive effect on the enterprises green technological innovation in industries with low concentration degree at the level of 5%. The development of digital finance is indeed more beneficial to green technological innovation for competitive enterprises that are not valued by the traditional financial system. According to the corporate life cycle, digital finance only produces positive promotion of green technological innovation activities for growth enterprises at the level of 1%. The above results show that digital finance has a stronger support for green technological innovation of enterprises, where more financial resources are required to carry out green technological innovation, but it is more difficult to obtain guarantees under traditional financial systems. That is to say, the development of digital finance has a stronger positive impact on green technological innovation of enterprises with a strong higher impact by relieving the stubborn problem of “matching difficulty” of financial resources. Therefore, hypothesis 2b is supported.

*4.6. Does It Reduce “Supervision Difficulty”?* The quality of a company’s disclosure report can reflect its information transparency to a certain extent. The higher the information transparency, the more conducive it is to reduce information asymmetry [40] so that it is easier to obtain resources from the traditional financial system. In this part, enterprises are grouped according to the quality of environmental disclosure reports and environmental governance reports of listed companies, and the impact of digital finance on green technological innovation in enterprises with different information transparency is investigated, respectively.

The results in Table 5 show that, only for the sample of enterprises with low quality in environmental disclosure reports and environmental governance reports, the development of digital finance has a positive impact on green technological innovation, which is, respectively, significant at 1% and 10% levels. The results show that the development of digital finance is helpful to expand the supervision path of enterprise green technological innovation and increase corporate information transparency with insufficient performance in conventional information disclosure. Thus, more financial resources are obtained to support green technological innovation. Overall, digital finance has a stronger positive impact on green technological innovation of enterprises with weaker information quality by resolving the problem of “supervision difficulty.” Hypothesis 2c is supported.

*4.7. Mediation Effect Test.* The above research verifies that digital finance development can significantly positively affect the innovation of corporate green technology by resolving

TABLE 3: Regression results of financing heterogeneity.

	Financing constraints		Financial leverage	
	(1)	(2)	(3)	(4)
	High financing constraint	Low financing constraints	High financial leverage	Low financial leverage
	Greeninno	Greeninno	Greeninno	Greeninno
L.Dfina	0.4495** (2.527)	0.2820 (1.170)	0.8576*** (4.822)	-0.1621 (-0.709)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Industry effect	Yes	Yes	Yes	Yes
_Cons	-2.7317*** (-5.933)	-3.6914*** (-6.805)	-4.2192*** (-9.925)	-0.3192 (-0.504)
N	2791	2169	2705	2255
r2_a	0.13281	0.1797	0.1963	0.0649

t statistics in parentheses; \* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ .

TABLE 4: Regression results of enterprise characteristics heterogeneity.

	Industry concentration		Enterprise life cycle		
	(1)	(2)	(3)	(4)	(5)
	High concentration	Low concentration	Growth period	Maturity period	Decline period
	Greeninno	Greeninno	Greeninno	Greeninno	Greeninno
L.Dfina	0.0240 (1.076)	0.6299** (2.669)	0.6177*** (3.143)	0.1499 (0.570)	0.3642 (0.941)
Control variables	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes
Industry effect	Yes	Yes	Yes	Yes	Yes
_Cons	-3.3781*** (-7.803)	-2.6101*** (-5.590)	-3.0994*** (-6.295)	-3.5479*** (-5.985)	-2.8016*** (-2.748)
N	1131	1367	2303	1771	739
r2_a	0.2119	0.1021	0.1294	0.1490	0.0712

t statistics in parentheses; \* $p < 0.1$ , \*\* $p < 0.05$ , and \*\*\* $p < 0.01$ .

TABLE 5: Regression results of information quality heterogeneity.

	Environmental disclosure report		Environmental governance report	
	(1)	(2)	(3)	(4)
	High quality	Low quality	High quality	Low quality
	Greeninno	Greeninno	Greeninno	Greeninno
L.Dfina	0.3135 (1.181)	0.5038*** (2.919)	0.4041 (1.602)	0.3528* (1.940)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Industry effect	Yes	Yes	Yes	Yes
_Cons	-5.1182*** (-8.610)	-1.7592*** (-3.706)	-3.5259*** (-5.396)	-3.1869*** (-7.211)
N	1570	3229	1537	3262
r2_a	0.2314	0.0741	0.1616	0.1135

t statistics in parentheses; \* $p < 0.1$ , \*\* $p < 0.05$ , and \*\*\* $p < 0.01$ .

problems with low traditional financial efficiency, and green technological innovation activities need to be supported by external financing and internal financing. However, can digital finance change the enterprise's internal environment to support innovation of enterprise green technology? What is the support mechanism in the process? It is necessary to

further explore these problems. Based on the previous analysis, we select "financing costs (FC)" and "financial flexibility (FF)" as two effects and build a mediation effect model, such as type (2) - (4), the test number financial intermediary effect on the impact process digital finance on green technological innovation.



$$\begin{aligned}
\text{Greeninno}_{it} &= \alpha_0 + \alpha_1 \text{Dfina}_{it-1} + \alpha_2 C_{it-1} + \sum \text{Ind} + \sum \text{Year} + \omega, \\
\text{mediator}_{it} &= \beta_0 + \beta_1 \text{Dfina}_{it-1} + \beta_2 C_{it-1} + \sum \text{Ind} + \sum \text{Year} + \sigma, \\
\text{Greeninno}_{it} &= \gamma_0 + \gamma_1 \text{Dfina}_{it-1} + \gamma_2 \text{mediator}_{it} + \gamma_3 C_{it-1} + \sum \text{Ind} + \sum \text{Year} + \tau.
\end{aligned} \tag{2}$$

According to existing literature, there are various financial indicators that can reflect the financial flexibility of an enterprise. Among them, working capital can help to smooth the R&D investment of enterprises [41], so it is more suitable for deconstructing the impact mechanism of digital finance to green technological innovation. This part chooses standardized working capital as financial flexibility measure; the calculation formula is working capital divided by total assets. The financing costs are calculated by the formula of financial expenses divided by total liabilities.

The results in Table 6 show that digital finance significantly reduces the financing costs of enterprises, and the financing costs have a mediation effect between green technological innovation and digital finance, and both of them are significant at the 1% level. At the same time, digital finance is positively associated with financial flexibility and also plays a significant mediation effect on the promotion of green technological innovation by digital finance, and its significance remains above 5%. The results show that digital finance can significantly promote corporate green technological progress by reducing corporate financing costs and improving financial flexibility. Thus, hypotheses 3 and hypothesis 4 are supported.

**4.8. Robustness Test.** In this paper, three methods are used to conduct robustness tests. First, replace the empirical model. Considering the dependent variable green patent for numerical shows continuous integrity distribution and the characteristics of the zero value accumulation, using Tobit model; at the same time, control “time multiplied by industry” method of high-order joint fixed effects on empirical model robustness check; inspection results are shown in model (1) in Table 7; the relationship between coefficients changes slightly, but still keep at least 5% level of significance. Second, change the sample selection. The samples of enterprises that have never been applied for green patents are eliminated, and only the samples of enterprises that have been in stages of green technological innovation are considered. As shown in model (2), the test results show no substantial changes. Third, replace key variables. The number of green invention patent applications, the measurement index of the dependent variable, was replaced by the total number of green invention patent applications (GreenInnoAll). As shown in model (3), the test results did not change substantially. The robustness tests show that the empirical results of this paper are robust.

## 5. Discussion and Implications

**5.1. Conclusions and Discussion.** Green technological innovation carried out by enterprises, which plays an important role in improving environmental quality, is an

activity that requires a large amount of financial support. Digital finance is crucial to the support. This paper sought to investigate the impact of digital finance on green technological innovation. The research sample was obtained from listed manufacturing companies of China from 2011 to 2018. The hypotheses set are tested by a two-way fixed effect model; combined with sample comparison analysis and mediation effect analysis, the following conclusions are drawn.

First, digital financial development can significantly promote enterprises’ green technological innovation in various aspects. From the three dimensions of digital finance, both the coverage and use depth of digital finance development positively affect green technological innovation, while the influence of digitization degree is not significant. This shows one vital path to reveal that digital financing function is building digital financial networks that include more financial institutions and enterprises and then promoting the in-depth nesting between various financing businesses and digital financial networks. To be specific, more financial institutions and enterprises should first use digital finance, that is, join the digital financial network. On the basis of it, the possible business interactions between financial institutions and enterprises and between enterprises should be deeply explored. In this path, digital finance is useful to reduce financial costs and improve financial efficiency and then be the financial support of enterprises. This result is similar to Demertzis (2018) and added more details of the function of digital finance.

Second, the development strength of digital finance makes up for the problems of “financing difficulty,” “matching difficulty,” and “supervision difficulty” faced by enterprises in external financing. For many enterprises that need green technological upgrading, there are gaps between green R&D and external financing support in traditional financing systems. These gaps caused by numerous reasons, essentially information asymmetry, can be to some extent bridged by digital finance. This result supplies more pieces of evidence to the effects of digital finance on enterprises with different characteristics.

Third, the development of digital finance can improve the internal financing of enterprises’ green technology innovation by reducing financing costs, improving financial flexibility. This helps enterprises to effectively carry out green technological innovation activities. This conclusion further verifies the improvement of digital finance on the financing environment of enterprises and helps to increase the understanding of the impact of digital finance development on the internal financial situation of enterprises.

**5.2. Public Policy Implications.** Some policy implications are provided. First of all, policies that support the development

TABLE 6: The mediation effect test.

	Financing costs			Financial flexibility		
	(1) Greeninno	(2) FC	(3) Greeninno	(4) Greeninno	(5) FF	(6) Greeninno
L.Dfina	0.3555** (2.425)	-0.0041*** (-3.602)	0.3154** (2.146)	0.3555** (2.425)	0.0536** (2.206)	0.3336** (2.269)
FC			-9.8262*** (-4.401)			
FF						0.4069*** (4.244)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry effect	Yes	Yes	Yes	Yes	Yes	Yes
_Cons	-2.9955*** (-8.753)	0.0109*** (5.355)	-2.8881*** (-8.481)	-2.9955*** (-8.753)	0.5245*** (9.808)	-3.2082*** (-9.214)
N	4960	4960	4960	4960	4956	4956
r2_a	0.1189	0.5360	0.1220	0.1189	0.5777	0.1217

*t* statistics in parentheses; \* $p < 0.1$ , \*\* $p < 0.05$ , and \*\*\* $p < 0.01$ .

TABLE 7: Robustness test.

	(1) Greeninno	(2) Greeninno	(3) GreeninnoAll
L.Dfina	0.4505** (2.322)	0.3978*** (2.592)	0.2866* (1.856)
Control variables	Yes	Yes	Yes
Time $\times$ industry	Yes		
Time effect		Yes	Yes
Industry effect		Yes	Yes
_Cons	-3.3920*** (-6.256)	-3.0312*** (-8.496)	-2.3086*** (-6.547)
var(e.Greeninno)	2.1222*** (39.576)		
N	4960	4522	4960
r2_a		0.1051	0.1387

*t* statistics in parentheses; \* $p < 0.1$ , \*\* $p < 0.05$ , and \*\*\* $p < 0.01$ .

of digital finance are necessary. The government should encourage financial institutions to develop digital finance-related businesses and apply them to more business scenarios to help build a broad digital financial network. On the premise of preventing financial risks, digital financial development policies should be given opportunities to try and make mistakes. More importantly, the government should help promote the construction of digital infrastructure at the national level and cultivate professionals who know both digitization and finance, to create favorable conditions for the development of digital finance. Secondly, the advantages of digital finance should be taken into account when formulating green finance policies. The government should encourage enterprises to make full use of the services provided by digital finance, as well as join the digital finance network, in order to promote green technological innovation. In this way, the advantages of efficient collection and processing of information in digital finance contribute to improving information quality of enterprises' green technological innovation, which not only give high-quality projects more financing but also give the process of green technology innovation more supervision to ensure the quality. Thirdly, the government should guide

enterprises to make full use of digital financial services, adjust financing structure, reduce financing costs, and increase financial flexibility, in order to avoid tight cash flow jeopardizing enterprises' green technology innovation.

This paper has attempted to robustly test these hypotheses, but there remain some limitations and suggestions for future research. First, this paper tests and confirms that digital finance positively affects green technological innovation, but it does not further explore the sustainability of this impact, which is worthy of research. Second, mediation effect analysis only discusses the influence of internal factors of the enterprise, and the mediation effect of external factors of the enterprise needs further discussion.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Acknowledgments

This work was funded by the Digital Economy Research Institute of the Zhongnan University of Economics and Law Xinglian Mango Fund “Hubei Digital Economy Development Research.”

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