frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 24 March 2023
DOI 10.3389/fenvs.2023.1122318

Check for updates

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 12 December 2022
ACCEPTED 16 March 2023
PUBLISHED 24 March 2023

CITATION
Yu Y, Li Y, Ni T and Gao C (2023), The impact of internet finance on green technology innovation in manufacturing companies --mediating role based on financing constraints.
Front. Environ. Sci. 11:1122318.
doi: 10.3389/fenvs.2023.1122318

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The impact of internet finance on green technology innovation in manufacturing companies --mediating role based on financing constraints

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To empirically analyze the relationship between internet finance and green technology innovation of manufacturing firms, this paper selects listed manufacturing firms from 2011 to 2020 as the sample. A panel regression model is then constructed and a causal stepwise regression test is used to examine the mediating effect of financing constraints on the role of internet finance in green technology innovation. The results show that the growth of Internet finance can significantly alleviate the financing problems of industrial enterprises and promote their adoption of green technologies. Further research found that enterprises in less developed areas in central and western China, in regions with weaker environmental regulations and smaller size, play a greater role in promoting green technology innovation. Consequently, improving the incentive system for Internet finance to promote green technology innovation in enterprises can effectively link the development of Internet finance and green innovation in enterprises, promote the development of ecological civilization, and serve as an important decision-making tool to help China achieve its "double carbon" goal.

KEYWORDS

internet finance, green technology innovation, manufacturing enterprises, financing constraints, mediating effect

1 Introduction

China's manufacturing industry has made incredible progress since the reform and opening up, both in terms of overall size and technological depth. High-quality manufacturing development is hindered by traditional extensive development, which causes China's economic growth and pollution to remain in the front part of the environmental Kuznets curve for a long period of time. Green transformation and manufacturing development have been elevated to a national strategic level by the "Made in China 2025" program, which explicitly calls for "accelerating green transformation and upgrading of the manufacturing industry" The report of the 20th National Congress of the Communist Party of China further emphasized the need to jointly promote carbon reduction, pollution reduction, green expansion and economic growth, and promote intelligent and green development of the manufacturing industry.

Innovation in science and technology is increasingly becoming the basis of economic and even national competitiveness (Yu et al., 2022a). In 2019, the National Development and

Reform Commission and other ministries also issued the "Guidance on Building a Market-Oriented Green Technology Innovation System." An important step in implementing the new development concept of "Innovation, Coordination, Green, Share" is the development of "green technology innovation," which refers to technology innovation activities aimed at saving resources and energy and preventing, eliminating or reducing environmental pollution and damage. Green technology innovations are a crucial strategic tool to achieve sustainable development of enterprises. They can increase the market value of a company's goods, reduce the cost of environmental investment, and increase the utilization rate of a company's resources, giving the company a competitive advantage (Jaffe, 1995). According to some researchers, proactive green technology innovation also has a significant positive impact on the financial performance of enterprises (Qing et al., 2022). In today's dynamic global climate, environmental management is becoming increasingly important, and more and more enterprises are willing to invest more in green technology development (Jiang and Tian, 2014). However, according to Wanhong et al. (2013), green technology innovation is characterized by strong externalities, long cycles, expensive investment, and high risks. The question of how to consistently and effectively support green technology innovation in manufacturing enterprises has become a practical challenge to be addressed in today's highly unstable market and technology environment.

In the short term, R&D investment in green technology innovation will reduce the productive investment of enterprises, but it will also increase the capital requirements of the product and make it more difficult for enterprises to access finance (Liang and Liu, 2022). Therefore, financial resources are crucial in promoting entrepreneurial innovation in green technologies and achieving environmental policy goals. The advantages of financial instruments such as capital, credit, and the market can be used to support enterprises' efforts to protect the environment. According to Jun (2016), the main function of the incentive mechanism in resource allocation should be capital allocation. The financial environment can also have a significant positive impact on the efficiency of green financing (Yu et al., 2022b).

Internet finance is the result of the increasing use of Internet technologies in financial activities due to the development of technologies such as the Internet, cloud computing and Big Data. According to Huang and Zhuo (2018), the term "Internet finance" broadly refers to the use of digital technologies by both traditional financial institutions and Internet companies to facilitate financing, payment, investment, and other innovative financial business models. Internet finance integrates digital technologies such as the Internet, cloud computing, Big Data, and blockchain into the financial sector to provide long-term access to a variety of financial services offered by different financial institutions and effectively promote the enterprise-wide adoption of green technological innovations (Zhang, 2023). On the one hand, with the advantages of networking and information technology, Internet finance can enhance financing convenience while increasing financing efficiency and reducing costs. On the other hand, digital information technology transforms the credit system, enables Big Data to make scientific and thorough assessments of all market participants, lowers the cost of identifying green innovation projects, strengthens the risk control of green innovation projects, and provides efficient allocation of financial market resources (Li, 2022). Therefore, it is not yet known whether Internet finance can promote green technology innovation in industrial enterprises. Greening and digitalization have emerged as two key concepts in enterprise development. Many companies face the challenge of putting digitalization and greening into practice. Can Internet finance, a byproduct of the digital economy, help companies become greener and give them a competitive edge? Discussing this question in light of the inevitable trends of digitalization and greening is extremely practical.

In this study, listed A-share manufacturing companies from 2011 to 2020 are used as the sample. A panel regression model is constructed to empirically analyze the relationship between Internet finance and green technology innovation of manufacturing firms, a causal stepwise regression test is used to examine the mediating role of financing constraints on the role of Internet finance on green technology innovation, and whether the impact of Internet finance on green technology innovation is positive or negative.

The main contributions of this study are: First, from the perspective of Internet finance, this study extends existing research on the financial market and corporate green technology innovation. The study concludes that the growth of Internet finance contributes to the realization of the incentive mechanism for the allocation of financial resources, and emphasizes the contribution of financial market growth to the promotion of innovation in green production enterprises from the perspective of Internet finance. The relationship between macrofinancial markets and microenterprise behavior is further promoted by this discovery. Second, using a mediation effects test model, this study investigates and evaluates the impact paths and effects of Internet finance on green technology innovation of manufacturing enterprises from the perspective of financial constraints. Moreover, through the empirical investigation of the transmission mechanism of the impact of green technology innovation of enterprises, it becomes clear that financing constraints play a mediating role in the impact of Internet finance on green technology innovation of manufacturing enterprises, which provides a theoretical basis and guidance for the in-depth discussion on the healthy development of Internet finance and the formulation of related policies in China.

The remaining parts of this paper are organized as follows: The second part is devoted to the theoretical analysis and research hypothesis, the third to the research methodology and index selection, the fourth to the main regression results and analysis of Internet finance and green technology innovation of manufacturing enterprises, the fifth to a heterogeneity analysis of Internet finance for green technology innovation of manufacturing enterprises, and the sixth to the conclusion.

2 Literature

Green technology innovation is defined as adhering to ecological principles and ecological economic laws, conserving resources and energy, preventing, eliminating or minimizing pollution and damage to the environment, and minimizing the negative ecological impact of "environmentally friendly" or "less harmful"

technologies, processes and products (Yu et al., 2022a). Green technology innovations include various technological advances as well as product design, environmentally friendly materials, environmentally friendly processes, environmentally friendly equipment, recycling, and packaging (Aguilera-Caracuel and Ortiz-de-Mandojana, 2013). Most of the research on green technology innovation focuses on two main areas: One is measuring the efficiency and performance of green technology innovation, for example, Yu et al. (2022a) measured the efficiency of green innovations in 64 resource-based cities in China using the super-efficient SBM model with non-expected output, Moran's I index and a spatial econometric model (Yu et al., 2022a; Wang et al., 2016) used the DEA method to measure regional green growth performance and green technology innovation efficiency in China from 2007 to 2011. On the other hand, studies have been conducted on the drivers of green technology innovation. Research on the drivers of green technology innovation has been analyzed by scholars mainly from the perspectives of institutional theory, market theory and NRA (Yang and Chai, 2015). From the institutional perspective, the existing literature mainly analyzes industrial policy (Lai and Cheng, 2016), finance and technology investment (Miao et al., 2019) and institutional environment (Shi and Yuanyuan, 2022); from the market perspective, the existing studies analyze customer demand, equity and investor demand; in terms of the NRA viewpoint, the literature mainly analyzes a cultural and green viewpoint. It can be simply concluded that a systemic project, primarily consisting of policy, institutions, and factor supply, which serves as the foundation for the growth of green technological innovation activities in enterprises, is necessary to effectively drive green technological innovation in microenterprises. Without the necessary financial, policy, and market support, firms will not be able to fully leverage their own factors, and their technological innovation efforts will likely remain stuck in a low-level equilibrium deficit.

There are many studies on enterprise green technology innovation in the digital economy, and the main literature has examined the impact of enterprise digital transformation on enterprise green technology innovation and the combination of enterprise digital transformation and innovation activities. For example, Shi and Yuanyuan (2022) used hierarchical regression and fsQCA methods to empirically validate the effects of the adoption process of digital green innovation activities and digital green knowledge creation on digital green innovation performance, and investigated the moderating role of digital green risk perception and digital green complexity perception in the integration of digital technologies with green innovation and production processes. The application of Big Data by companies affects their green innovation activities (El-Kassar and Singh, 2019). Manufacturing enterprises are actively using the new generation of information and communication technologies such as Internet Big Data and artificial intelligence to solve the practical problems of green innovation by moving from internal transformation to external coordination and from single-point application to global optimization (Shi et al., 2020a; Yin et al., 2020b). The digital transformation of enterprises helps to achieve green production, i.e., saving energy and reducing consumption through digital technology, smart production, improving production efficiency, and achieving the same or even higher production value with less consumption and emissions (Acquah et al., 2021; Mandal et al., 2021). All these studies in the literature show that digital transformation in enterprises can improve green innovation performance. However, the rapid development of digital technology has not only changed the internal operations of enterprises, but also the external environment on which they depend, especially the financial environment. Internet finance is a product of the integration of digital technology and traditional finance. The development of Internet finance can promote resource allocation and mitigate the financing constraints of green technology innovation. The development of Internet finance can effectively improve the problem of insufficient resource liquidity and resource mismatch that exists in the traditional financial system, improving the efficiency of the flow of unused resources between market participants (Demertzis et al., 2018) and making innovation resources flow in a timely manner to enterprises that need to carry out green technology innovation. Internet finance can also mitigate firms' financing constraints while optimizing resource allocation. Therefore, this paper explores how the application of digital technology in financial services affects firms' green technology innovation activities from the perspective of their external finance supply.

Finance plays an important role in economic growth (Long and Lin, 2018). However, China's bank-dominated financial supply structure has not adapted to the requirements of industrial structure modernization (Wu and Liu, 2017), and instead has a detrimental effect on the modernization of the manufacturing sector. The insufficient effective financing demand of manufacturing enterprises, the structural imbalance on the supply side of financing, the information asymmetry, and the challenges SMEs face in accessing credit services make it difficult to provide financial support for high-quality manufacturing development in the current environment (Ren and Jia, 2019). At present, studies on the impact of Internet finance on green technology innovation have mainly been examined at three levels: Macro, meso and micro levels. At the macro level, internet banking alleviates regional financial constraints and directs social capital flows to support the modernization of industrial structures, thereby promoting regional technological innovation (Nie et al., 2021). At the meso level, Internet finance promotes the innovation ability and willingness of innovation subjects, which leads to the upgrading of industrial structure (Du and Wang, 2022). It also directs the innovation direction of the industry. The "incremental supplement" and "inventory optimization" functions of Internet finance are used at the micro level to solve financing problems for enterprises and successfully resolve traditional financial inconsistencies, which supports the technological innovationof enterprises (Tang et al., 2020).

In summary, this study has benefited from the concise findings of the current literature. However, very few of them have addressed financial growth as a motivator for green technological innovation in firms. In terms of research methods, scholars have mainly developed regression models at the provincial, municipal, and industry levels, lacking firm-level microdata and very few thorough and in-depth discussions of heterogeneity. The aim of this study is to fill this knowledge gap by identifying linkages between Internet finance and green technology innovation in manufacturing firms and exploring

the impacts and intermediary transformation processes between them.

3 Theoretical analysis and hypothesis derivation

3.1 The role of internet finance on green technology innovation in manufacturing companies

The real economy and even technical innovation activities are significantly affected by finance, and the efficient provision of finance can directly affect these activities (Jia et al., 2017). The structural transformation and high-quality development of China's economy, which are necessary for the rapid progress of Internet finance, have been greatly hindered by the underdeveloped financial system in China and the lack of traditional financial services (Huang and Zhuo, 2018). With the support of information technologies such as the Internet, cloud computing, and Big Data, Internet finance has ameliorated the problems of high risk premium and high operating cost in traditional financial services caused by information asymmetry (Hao, 2018), and thanks to its own networking and informatization advantages, it has provided technical support to expand the scale and scope of financial services (Guo et al., 2017). Internet finance can thus reduce the cost of financing green technology innovations in manufacturing companies, while opening up new options for these companies' green technology innovation efforts.

Theoretically, financial growth has a significant stimulating effect on the development of green technologies. To achieve high-quality development, a variety of new technologies, industries, and other innovative projects require financial support. On the other hand, market-oriented financial solutions, especially green financial solutions, can also be used to eliminate backward production capacity with high pollution and high emissions, thus supporting green technological innovation. By virtue of its own network and information technology, with the support of information technologies such as the Internet, cloud computing, and Big Data, Internet finance can greatly improve the problems of high risk premium and high operating cost in traditional financial services due to information asymmetry (Hao, 2018) and provides technical support for expanding the reach and scope of financial services (Guo et al., 2017). Internet finance can thus reduce the cost of financing green technology innovation in manufacturing enterprises, while opening up new options for these enterprises' green technology innovation efforts. The beneficial effect of the development of Internet finance on the adoption of green technologies by manufacturing firms is evident in two ways: First, Internet finance provides enterprises with a wider range of financing options, lowers the barrier to enterprise financing, and effectively fills the gap created by a lack of traditional financing, as Internet finance channels are more advantageous than traditional ones in terms of cost and volume (Fengqi, 2015). Second, Internet finance uses digital information technology to improve the information verification and risk assessment capabilities of both enterprises and individuals. This greatly improves the service efficiency of financial institutions while reducing transaction costs, including information processing and risk assessment (Hao, 2018), lowering the financing costs of enterprises and providing sufficient financial support for their green technology. In addition, thanks to information technologies such as Big Data, cloud computing, Internet, and blockchain, Internet finance helps process enormous amounts of data at lower costs and risks (GomberKauffman et al., 2018). The expansion of Internet finance has accelerated the integration of financial services with the green industry, and the use of information technology to mine and analyze huge amounts of data makes it possible to match financial resources with the risk characteristics of enterprises' green innovation projects, greatly improving the effectiveness of financial resource allocation and risk management capacity (Song et al., 2019) and promoting the growth of green technology innovation.

In conclusion, this paper puts forth the claim:

Hypothesis 1. The growth of online finance has encouraged manufacturing companies to adopt green technology.

3.2 The role of financing constraints in the impact of internet finance on green technology innovation in manufacturing companies

Green technology innovation initiatives in manufacturing companies are not just about one aspect of the business. The company's green technology innovation efforts encompass everything from research and development of green technologies to the introduction of green product manufacturing or processes (Miao et al., 2019). The problem of high financing and adjustment costs affects green technology innovation activities as much as other types of innovation. Due to the information asymmetry between the company and the investor, the investor is likely to impose many constraints on the company when investing capital, which has a negative impact on the company's green technology innovation (Wu et al., 2022). Alternatively, the investor may forego the investment directly, increasing the company's financing costs. Innovations in green technology require significant ongoing investment in human and material resources. Innovations in green technology require significant ongoing investment in human and material resources. The research and development stage of green technology requires significant capital investment, and due to the information asymmetry between enterprises and investors, it is very likely that investors will impose many restrictions on enterprises when investing funds, which will affect the innovation of green technology of enterprises, or investors will directly abandon their investment, which will correspondingly increase the financing cost of enterprises. Once the enterprises start their green technology innovation activities, they will invest many resources and the input will exceed the output for a short period of time, which will make it impossible for the enterprises to use cash for other purposes, resulting in high adjustment costs (Tang and Tang, 2010).

Due to a significant information asymmetry between providers of financial resources and companies, the existing underdeveloped financial system is unable to keep pace with the rapidly growing and increasing volume of economic activity. This leads to an imbalance

between supply and demand. Viewed from different angles and orientations, the features of internet finance can increase the quality and effectiveness of services for financial services companies (Temelkov and Gogova, 2018). Through technologies such as Big Data retrieval and information sharing, Internet finance can increase the speed of information flow while expanding the number of financial products. This can also speed up credit appraisal and screening to reduce financing costs and remove financing constraints for SMEs (Tsai and Kuan Jung, 2017), further increasing financing options so that companies have sufficient funds and resources to support green technology innovation activities rather than being prevented from doing so.

In conclusion, this paper puts forth the claim:

Hypothesis 2. By easing their financial limitations, the growth of internet finance is supporting the use of green technology by manufacturing companies, i.e., the financial restrictions have a mediating effect on the impact of the growth of internet finance on green technology adoption.

3.3 Heterogeneity analysis of internet finance for green technology innovation in manufacturing companies

1. There are significant differences in the level of economic development, human capital, and scientific and technological innovation between the eastern coastal regions and the central and western inland regions when examining the impact of Internet finance on the green technological innovation capability of manufacturing enterprises from the perspective of the region where the production urn is located. This may also complicate the relationship between the impact of Internet finance and manufacturing innovation ability in these areas (Zheng and Zhao, 2021). The impact of Internet finance on green technological innovation of manufacturing enterprises may be inhibited by the higher level of economic development, better financial system, and overall higher awareness of environmental protection in eastern coastal regions (Qian et al., 2015).
2. When the promotion effect of Internet finance on green technological innovation of enterprises is studied from the perspective of environmental regulation, it may also vary depending on the location of enterprises and the degree of environmental control. According to Shichun et al. (2012), there are differences in the incentive effect of different environmental regulation policies on enterprises' technology innovation, and the government can improve the incentive effect of enterprises' green technology innovation by prescribing the stringency of environmental regulation.

In regions with a higher degree of environmental regulation, the government has stricter control over pollution, and enterprises need to implement green technology innovation to reduce pollution fines and environmental management costs and improve their own environmental management capabilities. Compared with the higher degree of environmental regulation, the promotion of green technology innovation by enterprises is inhibited by Internet finance. In areas with a higher degree of environmental regulation, the government has stricter control over pollution, and enterprises are required to engage in green technology innovation activities to reduce the price of pollution penalties and environmental management costs, as well as improve their own environmental management capabilities. The promotion of green technology innovation by enterprises through Internet finance is hindered compared to the more stringent environmental regulations.

3. In terms of company size, SMEs benefit more from the ability of Internet finance to overcome financial bottlenecks. SMEs are more reliant on external financing for their technological innovation activities because, compared to large firms, they are smaller and have fewer internal resources, most of which are needed to sustain their operations. Second, there is a larger knowledge gap between SMEs and external investors: first, small and medium-sized enterprises (SMEs) cannot afford to hire external organizations to audit and disclose information, so their information transparency is low. As a result, it is difficult for outside investors to evaluate SMEs' investment analysis, which increases borrowing costs and raises financing costs for SMEs. Internet finance supported by information technologies such as Big Data, the Internet and blockchain can accurately evaluate SMEs, improve the transparency of SMEs' information, reduce information asymmetry to a greater extent, and provide accurate financial services to SMEs, which promotes the development of green technology in SMEs.

The Hypothesis 3a, Hypothesis 3b, and Hypothesis 3c in this work is based on the analysis above.

Hypothesis 3a. Inland manufacturing businesses in the central and western regions are more significantly impacted by Internet finance than their counterparts in the more developed eastern regions.

Hypothesis 3b. Internet finance plays a bigger role in encouraging green technology innovation in manufacturing companies in regions with a lower level of environmental regulation than it does in areas with a greater level of environmental regulation.

Hypothesis 3c. Compared to large companies, SMEs see a greater reduction in financial constraints thanks to Internet finance, which has an impact on the development of green technology innovation in SMEs.

In conclusion, Figure 1 depicts the conceptual model of this paper.

4 Empirical study design

4.1 Sample selection and data sources

Taking into account data availability, this paper selects A-share manufacturing listed companies from 2011 to 2020 as the research sample. The eligible conditions for sample selection are: excluding companies with ST in any year during the study period; excluding companies with net profit loss in any year during the study period.

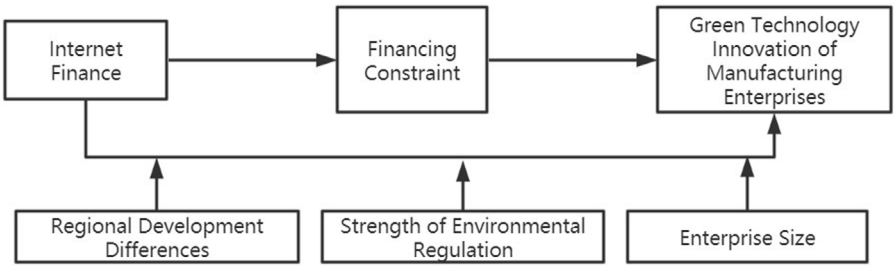

FIGURE 1
Conceptual model.

After the screening of the above conditions, 2,409 listed companies with a total of 15,416 sample observations were finally selected. To avoid the effect of outliers, all continuous variables are Winsorized at the upper and lower 1% level. The financial data of listed companies were obtained from the Cathay Capital (CSMAR) database, and all the empirical analysis processes were completed by statistical software such as Excel and Stata 16.0.

4.2 Model setting and variable definition

4.2.1 Explained variables

Company green technology innovation (GTI): This paper refers to the research methods of Qi et al. (2018) and Li and Xiao (2020), and matches the IPC classification numbers of patents retrieved from the "International Patent Green Classification List" launched by the World Intellectual Property Organization in 2010 and the listed patents retrieved from the State Intellectual Property Office of China (SIPO). The number of green patent applications per year was obtained by matching the patent types of listed companies retrieved from the "International Patent Green Classification List" launched by the World Intellectual Property Organization in 2010 and the patent types of listed companies retrieved from the State Intellectual Property Office of China (SIPO).

4.2.2 Explanatory variables

Since Internet finance is a new thing, the representative data currently available are not abundant. A review of the relevant literature reveals that most of the existing literature uses a single indicator to measure the level of Internet development, which is limited to only one aspect of the development level. Zou et al. (2017) used the third-party payment amount as an index of Internet finance to study the impact of Internet finance on the systemic risk of Chinese commercial banks. Yang et al. (2018) measures the level of development of Internet finance in China through four aspects: payment methods, resource allocation, risk control, and information processing. Among the self-constructed indices, the China Digital Inclusive Finance Index is more authoritative and comprehensive, and is widely used in the analysis and research of Internet finance.

To comprehensively reflect the development level of Internet finance, this paper selects the China Digital Inclusive Finance Index as the Internet finance index, which measures the three dimensions of the breadth of coverage, depth of use and digitalization, taking into account the breadth and depth of Internet finance development, as well as the comparability of the index horizontally and vertically. Therefore, this paper adopts the data of 31 provinces in mainland China from 2011 to 2020 of this index as the Internet finance index.

4.2.3 Mediating variables

There are three main approaches to the measurement of financing constraints in the literature: the first approach is to use a single indicator as a constraint index, with indicators such as interest coverage multiple, dividend payout ratio, and asset size; the second is to construct an index with multiple variables, such as the WW index and ZFC index; the third is to build quantitative models, such as the investment-cash flow model and the cash -cash flow models. Since a single index cannot comprehensively measure the degree of financing constraints of companies and is easily disturbed by other factors, its robustness is difficult to guarantee, while there are strict assumptions for constructing indices with multiple indicators, and the applicability to Chinese companies is yet to be tested, the quantitative model cannot truly reflect the limitations of industry characteristics and financing constraints faced by companies. Therefore, this paper refers to the KZ index measurement method and selects four indicators: cash stock (cash), current ratio (cr), total assets growth rate (tag), and return on net assets (roe) to construct the financing constraint index (FCI) to measure the degree of financing constraint from four aspects: cash flow, solvency, development ability, and profitability, respectively. The indicators for constructing the financing index and their calculation methods are shown in Table 1.

This paper uses a binary logistic model regression analysis to construct indicators of financing constraints.

$$FCI_{i,t} = \alpha\beta_1 cash_{i,t} + \beta_2 cr_{i,t} + \beta_3 tag_{i,t} + \beta_4 roe_{i,t}$$

The higher the financing constraint index, the higher the degree of financing constraint received by the company. This paper constructs financing constraint dummy variables based on interest coverage multiples, categorizing those greater than the median as the low financing constraint group and those less than the median as the high financing constraint group. The four variables are first grouped together to test for differences in means, and the results are shown in Table 2. The differences in means of each indicator are significant at the 1% level, indicating that the four variables are well differentiated under different

TABLE 1 Table of variables for the construction of the financing constraint index FCI.

Variable name	Variables conform to	Calculation method
Cash Inventory	cash	Cash and other cash equivalents/total assets at end of period
Current Ratio	cr	Current assets at end of period/Current liabilities at end of period
Total assets growth rate	tag	(Total assets at the end of the period—Total assets at the end of the previous period)/Total assets at the end of the previous period
Return on Net Assets	roe	Net income/average net assets

TABLE 2 Variable mean difference test for the financing constraint index FCI.

Variables	Grouping	Average value	Standard deviation	Mean difference	Significance of difference
cash	Low financing constraints	0.1670	0.1251	0.0407	19.8901***
	High financing constraints	0.2077	0.1288		
cr	Low financing constraints	2.0801	2.3478	0.9686	24.1861***
	High financing constraints	3.0488	2.6174		
tag	Low financing constraints	0.1938	2.0982	0.0647	2.2865**
	High financing constraints	0.2911	3.0900		
roe	Low financing constraints	0.0106	0.1661	0.0977	46.8767***
	High financing constraints	0.1082	0.0765		

TABLE 3 Logit regression results for the financing constraint index FCI.

Variables	Coefficient	Z-statistic	Clustering robust standard error	Significance
cash	0.0479	0.25	0.1922	0.803
cr	−0.1612	−12.22	0.0132	0.00
tag	−0.0038	−0.74	0.0052	0.00
roe	−11.7828	−29.83	0.3950	0.00
Cons	1.2291	28.48	0.0432	0.00

TABLE 4 Variable definitions.

Variable type	Variable name	Variable symbols	Calculation method
Explanatory variables	Digital Inclusive Finance Development Index	difi	BYU Digital Inclusive Finance Index/100
Explained variables	Green Technology Innovation	GTI	Number of green patent applications, the natural logarithm of the number of applications plus 1 for the year
Intermediate variables	Financing Constraints Index	FCI	Logit regression construction
Control variables	Company size	size	Natural logarithm of total assets at the end of the period
	Business Growth	growth	Operating income growth rate
	Company Age	age	(Sample year—IPO year) + 1
	Annual	year	Dummy Variables

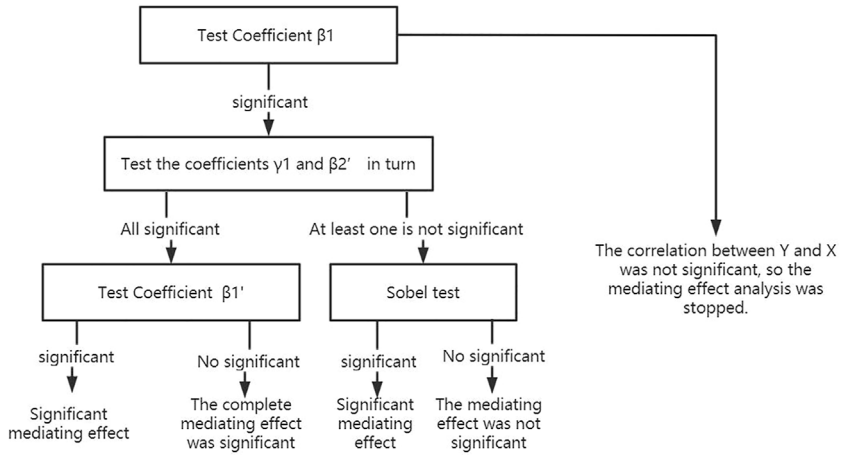

FIGURE 2
Steps of intermediate effect test.

groupings. Logit regression was performed on the model and the results are shown in Table 3. Based on the regression coefficients, the final financing constraint index is obtained as:

$$FCI_{i,t} = 1.2290 + 0.0479cash_{i,t} - 0.1612cr_{i,t} - 0.0038tag_{i,t} - 11.7828roe_{i,t}$$

4.2.4 Control variables

Many factors affect corporate innovation, and combined with the production and operation characteristics of listed companies, company size (size), total assets growth rate (tag), operating income growth rate (growth), and time to market (age) are selected as control variables in this paper, and annual dummy variables are also controlled in this paper.

The specific meanings and metrics of the variables involved in the model in this paper are shown in Table 4.

4.3 Model construction

This research first builds the benchmark regression model below to examine the association between Internet finance and green technology innovation of manufacturing companies.

$$GTI_{i,t} = \beta_0 + \beta_1 difi_{i,t} + \beta_2 controls_{i,t} + u_{i,t} + \vartheta_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where $GTI_{i,t}$ represents the output of green technology innovation results of company i in year t, β_0 is a constant term, $difi_{i,t}$ represents the level of internet finance development in company i's region in year t, $controls_{i,t}$ represents each control variables, $u_{i,t}$ represents the effect of each individual company, $\vartheta_{i,t}$ is the annual time effect, $\varepsilon_{i,t}$ is residual term, β_1 and β_2 represent the parameters that need to be estimated for the explanatory and control variables, respectively.

This paper adopts a mediation effect test procedure suggested by Zhonglin et al. (2004) to test the mediating role of financial constraints in the impact of Internet finance development on green technology innovation of listed manufacturing companies. The procedure's sum of the first and second type of error rates is typically lower than that of a single test, and it can perform both partial and full mediation tests. Figure 2 depicts the steps of this mediation effect test. Therefore, the following two models are built on the basis of the above model:

$$FCI_{i,t} = \gamma_0 + \gamma_1 difi_{i,t} + \gamma_2 controls_{i,t} + u_{i,t} + \vartheta_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$GTI_{i,t} = \beta_0{}' + \beta_1{}' difi_{i,t} + \beta_2' FCI_{i,t} + \beta_3' controls_{i,t} + u_{i,t} + \vartheta_{i,t} + \varepsilon_{i,t} \quad (3)$$

The specific test steps are as follows, and they are based on the stepwise regression analysis of mediating effects.

In the first step, it is concompanyed that Internet finance has an impact on manufacturing companies' adoption of green technologies. If model (1)'s coefficient β_1 of $difi_{i,t}$ is significant, it indicates that there is a direct relationship between Internet finance and green technology innovation in manufacturing companies, i.e., that the direct transmission mechanism is there. If so, move on to step two. The test is over if the coefficient β_1 of $difi_{i,t}$ is not significant.

The second phase is verifying how Internet finance affects financial restrictions. If the coefficient γ_1 of $difi_{i,t}$ in model (2) is significant, it means that funding restrictions are impacted by Internet finance.

The third step is to concompany the financing restrictions' mediating role in the relationship between corporate green technology innovation and Internet finance development. If coefficients $\beta_1{}'$ of $difi_{i,t}$ and β_2' of $FCI_{i,t}$ in model (3) are significant, then the mediation effect is substantial as well. Sobel test is required if there is only one significant coefficient between coefficient γ_1 of $difi_{i,t}$ in model (2) and coefficient β_2' of $FCI_{i,t}$ in model (3).

This paper also applies the following treatments to the regression: First, this paper treats the Internet finance index with a lag, which can help mitigate the reverse causality problem, considering the fact that it takes some time for Internet finance

TABLE 5 Descriptive statistics of main variables.

Variables	Average value	Standard deviation	Minimum value	Maximum value	Number of samples
GTI	0.756	1.114	0.000	7.083	15,416
difi	2.711	0.849	0.615	4.319	15,416
FCI	0.124	1.719	−4.965	12.217	15,416
lev	0.397	0.196	0.014	0.999	15,416
size	22.040	1.184	19.092	27.062	15,416
growth	3.460	386.320	−0.991	4.8e+04	15,416
age	9.624	6.991	1.000	30.000	15,416
tag	0.242	2.641	−0.972	254.455	15,416

TABLE 6 Correlation analysis of main variables.

Variables	GTI	FCI	difi	Size	Growth	Age	tag
GTI	1.0000						
FCI	−0.0251*	1.0000					
difi	0.1044*	−0.0357*	1.0000				
size	0.4962*	−0.0201	0.0832*	1.0000			
growth	−0.0000	−0.0051	−0.0129	0.0048	1.0000		
age	0.1603*	0.1483*	0.0261*	0.4128*	0.0125	1.0000	
tag	0.0290*	−0.0402*	−0.0141	0.0695*	0.1162*	0.0177	1.0000

to influence the green technology innovation actions of companies. Second, this paper controls for individual effects and time effects for testing.

5 Analysis and discussion of the main regression results of internet finance and green technology innovation in manufacturing companies

5.1 Descriptive statistics

Table 5 presents the descriptive statistics of the Internet Finance Index, the number of green patents of companies, and other company-level variables. From the results in Table 5, it can be seen that the valid sample is 15,416. The maximum value of the green technology innovation level index (GTI) of listed companies is 7.083, the minimum value is 0, and the mean value is 0.756, indicating that the green technology innovation level varies widely among different manufacturing companies. The maximum value of the internet finance index (difi) is 4.319, the minimum value is 0.615, and the mean value is 2.711, which indicates that there are differences in the development of internet finance among different regions. The financing constraint (FCI) has a maximum value of 12.217, a minimum value of −4.965, and a mean value of 0.124, which indicates that there are also large differences in the financing constraints faced by different companies.

TABLE 7 Multicollinearity results.

Variable	VIF	1/VIF
age	1.24	0.804875
size	1.23	0.814397
fci	1.03	0.967568
tag	1.02	0.979850
growth	1.01	0.986194
difi	1.01	0.991328
Mean VIF	1.09	

5.2 Correlation analysis

The Pearson test was employed in this study to examine the relationships between the variables, and the findings are displayed in Table 6. The expansion of Internet finance has, to some extent, encouraged the green technology innovation of companies, as evidenced by the considerable positive connection between green technology innovation variables and the Internet finance index, supporting Hypothesis 1. The rise of Internet finance has, to some extent, eased the funding constraint, which is in line with the expectation of this article, as indicated by the significant negative

TABLE 8 Regression results of Internet finance and green technology innovation of manufacturing companies.

Variables	(1)	(2)	(3)
	GTI	GTI	GTI
difi	0.209***		
	(3.456)		
Lagging Phase I difi		0.221***	
		(3.271)	
Two-phase lagged difi			0.241***
			(3.138)
size	0.467***	0.484***	0.501***
	(21.164)	(21.223)	(21.270)
growth	−0.000**	−0.000**	0.007
	(−2.134)	(−2.505)	(1.336)
age	−0.003	−0.003	−0.003
	(−1.001)	(−0.887)	(−1.046)
tag	−0.003	−0.009***	−0.010***
	(−0.744)	(−3.747)	(−3.763)
_cons	−10.319***	−10.721***	−11.114***
	(−21.555)	(−21.539)	(−21.539)
adj. R2	0.310	0.317	0.323
F	64.737	76.033	65.525
N	15,416	12,969	10,723

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

correlation coefficient between the Internet finance index and the financing constraint index. Regression is used in this study to further concompany the relationship between the pertinent variables.

5.3 Multicollinearity results

The variance inflation factor of each variable is calculated in this paper to avoid the potential for serious multicollinearity among the variables, which could affect the model results. The results are shown in Table 7, and the mean value of VIF is 1.09, indicating that there is no significant collinearity among the variables chosen in this paper.

5.4 Analysis and discussion of regression results of internet finance and green technology innovation in manufacturing companies

Given that there may be a lag in the impact of Internet finance on companies' green technology innovation, this paper also verifies the impact of Internet finance index on green technology innovation with one period lag and two periods lag, and the results are in columns (2) and (3), respectively. Column (1) in Table 8 displays the regression results of Internet finance and green technology innovation. The regression results show that Internet finance has a coefficient of 0.209, which is significantly positive at the 1% level, indicating that it can encourage green technology innovation in businesses and has an incentivizing effect on the adoption of green technologies by manufacturing companies. Accordingly, Hypothesis 1 is true. This result is consistent with the findings of Tang et al. (2020) and Demertzis et al. (2018). This indicates that the better the degree of Internet finance development, then the higher the level of green technology innovation output of companies. The results in columns (2) and (3) demonstrate that the coefficients of the Internet finance index with one lag and two lags, with coefficients of 0.221 and 0.241, respectively, are significantly positive at the 1% level. The coefficients of Internet finance with two lags are also marginally higher than those of Internet finance with one lag and no lag, which further suggests that there is some lag. This indicates that the development of Internet finance has helped to enhance the green technology innovation capability of companies, strengthen their core competitiveness in innovation, and demonstrate significant innovation momentum.

TABLE 9 Tests of mediating effects of financing constraints.

Variables	(1)	(2)	(3)
	GTI	FCI	GTI
difi	0.209***	−0.287***	0.205***
	(3.456)	(−3.677)	(3.391)
FCI			−0.014**
			(−2.108)
size	0.467***	−0.148***	0.465***
	(21.164)	(−6.525)	(21.179)
growth	−0.000**	−0.000	−0.000**
	(−2.134)	(−1.155)	(−2.200)
age	−0.003	0.046***	−0.002
	(−1.001)	(12.780)	(−0.735)
tag	−0.003	−0.024*	−0.004
	(−0.744)	(−1.900)	(−0.825)
_cons	−10.319***	3.024***	−10.277***
	(−21.555)	(6.229)	(−21.580)
adj. R2	0.310	0.044	0.310
F	64.737	35.907	61.224
N	15,416	15,416	15,416

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

5.5 Analysis and discussion of the results of the test of mediating effects of financing constraints

The impact of Internet finance on green technology innovation in manufacturing companies is examined in this paper using a causal

TABLE 10 Analysis of heterogeneity between Eastern and Midwestern regions.

Variables	East					Midwest				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	GTI	FCI	GTI	GTI	GTI	GTI	FCI	GTI	GTI	GTI
difi	0.051	−0.220*	0.048			0.965***	−0.377	0.962***		
	(0.526)	(−1.871)	(0.491)			(4.456)	(−1.094)	(4.444)		
FCI			−0.015*					−0.007		
			(−1.697)					(−0.792)		
difi1				0.047					1.063***	
				(0.439)					(4.540)	
difi					0.027					1.150***
					(0.222)					(4.254)
size	0.510***	−0.171***	0.507***	0.525***	0.544***	0.395***		0.395***	0.413***	0.427***
	(17.668)	(−6.229)	(17.667)	(17.638)	(17.866)	(13.516)		(13.517)	(13.473)	(13.179)
growth	0.005*	−0.007	0.005*	0.003	0.003	−0.000*	0.000	−0.000*	−0.000***	−0.002
	(1.816)	(−1.295)	(1.745)	(0.541)	(0.241)	(−1.883)	(0.396)	(−1.890)	(−2.899)	(−0.277)
age	0.001	0.049***	0.001	0.002	0.002	−0.009**	0.035***	−0.008**	−0.009**	−0.011**
	(0.164)	(10.537)	(0.370)	(0.459)	(0.417)	(−2.131)	(6.137)	(−2.016)	(−2.168)	(−2.298)
tag	−0.010***	−0.013	−0.010***	−0.012***	−0.013***	0.005	−0.055*	0.005	0.021	0.019
	(−3.817)	(−1.553)	(−3.794)	(−3.435)	(−3.470)	(0.829)	(−1.842)	(0.769)	(1.510)	(0.984)
_cons	−11.078***	3.534***	−11.024***	−11.445***	−11.848***	−9.363***	−0.205	−9.347***	−9.792***	−10.152***
	(−17.701)	(5.721)	(−17.701)	(−17.651)	(−17.751)	(−14.186)	(−0.560)	(−14.197)	(−14.139)	(−13.818)
adj. R^2	0.337	0.044	0.338	0.345	0.353	0.275	0.040	0.275	0.281	0.282
F	47.639	12.756	45.435	50.033	50.487	34.179	28.233	32.386	30.873	23.120
N	10,383	10,383	10,383	8,677	7,107	5,033	5,033	5,033	4,292	3,616

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

stepwise regression test, and columns (1), (2), and (3) of Table 9 present the regression results for the three models of the stepwise regression of mediating effects, respectively. The results in column (1) demonstrate that Internet finance and green technology innovation are significant at the 1% level, allowing the next part of the mediating effect test, i.e., testing the impact of Internet finance on financing limitations, to be conducted, and the results in column (2) demonstrate that the relationship between Internet finance and financial constraints is statistically significant at the 1% level, suggesting that Internet finance can free manufacturing companies from financial constraints. The regression results are in line with Hypothesis 2. The findings in column (3) demonstrate that the correlations between Internet finance and financial constraints are significant at the 1% and 5% levels, respectively, indicating that the mediating effect of financial constraints is significant and partial, i.e., Internet finance can encourage green technology innovation of manufacturing companies by easing financial constraints. This result is consistent with the findings of Wu et al. (2022) and Qi et al. (2018). A large number of empirical studies have verified that financing constraints inhibit technological innovation. Internet finance largely complements the shortcomings that exist in traditional finance by providing richer and more diverse financing tools, which in turn better serve the financial resource needs of microcompany subjects. With the help of the Internet financial platform, companies can obtain funds in a short period of time and at low cost, which to a certain extent reduces the financing constraint of companies.

6 Heterogeneous analysis and discussion of internet finance for green technology innovation in manufacturing companies

6.1 Analysis and discussion of the heterogeneity of the eastern and midwestern regions

The level of economic development and technological innovation in the eastern coastal region is much higher than that

TABLE 11 Regional environmental regulation heterogeneity analysis.

Variables	Weak environmental regulation					Strong environmental regulation				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	GTI	FCI	GTI	GTI	GTI	GTI	FCI	GTI	GTI	GTI
difi	0.305***	−0.528***	0.289***			0.134**	−0.083	0.134**		
	(3.736)	(−5.010)	(3.532)			(2.262)	(−0.824)	(2.266)		
FCI			−0.030***					0.002		
			(−2.961)					(0.251)		
difi1				0.316***					0.149**	
				(3.538)					(2.238)	
difi2					0.357***					0.146*
					(3.660)					(1.858)
size	0.434***	−0.122***	0.430***	0.456***	0.477***	0.502***		0.502***	0.508***	0.518***
	(15.352)	(−3.835)	(15.281)	(15.208)	(14.914)	(22.546)		(22.635)	(22.094)	(21.711)
growth	−0.000*	−0.000	−0.000*	−0.000	0.006	0.004	−0.074***	0.004	0.013	0.012
	(−1.757)	(−0.629)	(−1.759)	(−0.459)	(1.031)	(0.467)	(−3.817)	(0.478)	(1.104)	(1.020)
age	−0.007**	0.051***	−0.005	−0.008**	−0.010**	−0.000	0.032***	−0.000	0.001	0.000
	(−1.993)	(9.717)	(−1.506)	(−1.989)	(−2.245)	(−0.011)	(7.823)	(−0.039)	(0.205)	(0.071)
tag	0.007	−0.031**	0.006	−0.007	−0.014	−0.010***	−0.019*	−0.009***	−0.010***	−0.010***
	(0.850)	(−2.186)	(0.724)	(−0.539)	(−0.905)	(−5.267)	(−1.660)	(−5.278)	(−5.089)	(−4.829)
_cons	−9.632***	2.764***	−9.550***	−10.126***	−10.585***	−11.350***	−0.065	−11.357***	−11.437***	−11.573***
	(−15.517)	(4.149)	(−15.447)	(−15.350)	(−15.065)	(−23.802)	(−0.194)	(−23.920)	(−22.952)	(−22.421)
adj. R^2	0.304	0.058	0.306	0.313	0.323	0.320	0.034	0.320	0.325	0.327
F	38.799	42.587	36.335	40.575	31.292	57.434	9.837	54.746	57.747	57.490
N	7,701	7,701	7,701	5,978	4,414	7,715	7,715	7,715	6,991	6,309

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

in the central and western regions; therefore, the development of Internet information technology is faster and better in the eastern region, while the level of Internet technology development in the central and western regions is more backward. From this aspect of analysis, the level of development of Internet finance in the eastern region is higher, so the incentive effect on green technology innovation of manufacturing companies may also be stronger. However, from another aspect, the eastern region is more developed and has closer communication with foreign companies, and its environmental awareness is also better than that of the central and western regions, so the level of green technological innovation of companies in the eastern region itself is higher than that of the central and western regions, then, this may also weaken the incentive effect of Internet finance on green technological innovation. In order to study the regional heterogeneity of Internet finance on green technology innovation of manufacturing companies, this paper will divide the companies into two groups according to the regions they are located in, the eastern region includes Heilongjiang, Jilin, Liaoning, Hebei, Beijing, Tianjin, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan, and the regression results are obtained as Table 10.

The regression results show that according to column (1) (6), in the eastern region, the coefficient under Internet finance on green technology innovation is positive but not significant, while in the central and western regions, the coefficient of Internet finance is significantly higher than that of the eastern region and significant at the 1% level, which indicates that compared to the developed eastern region, the impact of Internet finance on the green technology innovation capability of manufacturing companies located in the central and western inland regions The effect is more significant, and the regression results of Internet finance with one and two lags show consistent [shown in column (4) (5) (9) (10)], and Hypothesis 3a is verified. In the eastern region, the Internet finance and financing constraints are significantly negative at the 10% level, indicating that Internet finance alleviates the financing constraints of manufacturing companies located in the eastern region to some extent, but the effect of Internet finance on financing constraints is not significant in the central and western regions.

TABLE 12 Company size grouping test.

Variables	Smaller group size					Larger groups				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	GTI	FCI	GTI	GTI	GTI	GTI	FCI	GTI	GTI	GTI
difi	0.310***	−0.405***	0.291**			0.080	−0.131	0.080		
	(2.672)	(−3.788)	(2.504)			(1.516)	(−1.307)	(1.512)		
FCI			−0.048***					−0.003		
			(−3.534)					(−0.448)		
difi1				0.309**					0.097	
				(2.473)					(1.595)	
difi2					0.328**					0.115
					(2.402)					(13)
growth	−0.000**	−0.000*	−0.000**	−0.000***	0.008	−0.002***	−0.010***	−0.002***	−0.006**	−0.006**
	(−2.438)	(−1.732)	(−2.510)	(−2.701)	(0.937)	(−2.728)	(−2.868)	(−2.734)	(−2.552)	(−2.378)
age	0.020***	0.017***	0.021***	0.022***	0.022***	0.001	0.066***	0.001	−0.000	−0.002
	(4.236)	(3.897)	(4.383)	(4.341)	(4.253)	(0.312)	(13.169)	(0.367)	(−0.017)	(−0.840)
tag	0.004	−0.017**	0.003	0.002	−0.000	0.074***	−0.972***	0.072***	0.084**	0.115***
	(0.902)	(−2.297)	(0.740)	(0.529)	(−0.022)	(2.965)	(−9.076)	(2.856)	(2.520)	(2.650)
_cons	−0.448***	0.221	−0.438***	−0.410**	−0.434**	−0.039	−0.412***	−0.040	−0.065	−0.003
	(−2.852)	(1.147)	(−2.787)	(−2.411)	(−2.360)	(−0.513)	(−2.613)	(−0.524)	(−0.741)	(−0.027)
adj. *R2*	0.132	0.022	0.136	0.132	0.133	0.042	0.112	0.042	0.043	0.043
F	31.836	50.846	29.905	32.443	32.717	13.566	21.716	12.710	12.814	10.923
N	7,708	7,708	7,708	6,986	6,219	7,708	7,708	7,708	5,983	4,504

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

6.2 Analysis and discussion of regional environmental regulation heterogeneity

The intensity of environmental regulation varies in different regions, so the impact of Internet finance on companies' green technological innovation may differ under different environmental regulation intensity. To examine whether there is regional environmental regulation heterogeneity of Internet finance on manufacturing companies' green technological innovation, this paper refers to Zhang et al. (2020) and selects the ratio of pollutant emissions to industrial value added in each province to measure each province's environmental The lower the pollutant emissions per unit of industrial value added, the greater the intensity of environmental regulation in that region. In this paper, two groups of strong environmental regulation and weak environmental regulation were divided according to the median of environmental regulation, and the influence of Internet finance on companies' green technology innovation was examined separately, and the results were obtained as shown in Table 11.

The results of the subgroup regressions show that the results in column (1) (6) find that the coefficient of Internet finance and green technology innovation in the subgroup with weaker environmental regulation is 0.305 and significant at the 1% level, while the coefficient of Internet finance and green technology innovation in the subgroup with stronger environmental regulation is 0.134, with a slightly lower coefficient than that of the region with weaker environmental regulation, and the significance is also weaker, only significant at the 5% level, and the regression results for Internet finance with one and two lags are also consistent. [Column (4) (5) (9) (10) results] This indicates that the incentive effect of Internet finance on green technological innovation of manufacturing companies is greater in regions with weaker environmental regulations, while in regions with stronger environmental regulations, local policies and more stringent controls on the environment require local companies to reduce pollution emissions, and in order to reduce environmental management costs, companies have to carry out green technological innovation, which will weaken the impact of Internet finance on companies' green technology innovation.

The results of the mediation effect test are in column (2) (3) (7) (8), and the results show that Internet finance is more likely to promote the financing constraints of companies in regions with weaker environmental regulations compared to companies in regions with stronger environmental regulations, and the

mediation effect of financing constraints is significant in the grouping of regions with weaker environmental regulations, while the mediation effect in the grouping of regions with stronger environmental regulations remains to be verified. The study concludes that Internet finance has a more significant role in promoting green technology innovation among companies in regions with lower environmental regulations than in regions with higher environmental regulations, and Hypothesis 3b is verified.

6.3 Analysis and discussion of company size heterogeneity

To examine whether there is company size heterogeneity in the green technology innovation of manufacturing companies by Internet finance, the full sample is divided into two groups of samples analyzed by the median of company size for larger companies and smaller companies, and the regression results are shown in Table 12.

The results of the company size grouping test show that the results in columns (1) and (6) show that the coefficient of Internet finance and green technology innovation is significantly positive at the 1% level in the smaller company size grouping, while the coefficient of Internet finance and green technology innovation is positive but not significant in the larger companies, and the regression results of Internet finance with one and two lags [columns (4) (5) (9) (10) columns] are also consistent with this result, which indicates that the incentive effect of Internet finance on green technology innovation is more significant for smaller manufacturing companies compared to larger manufacturing companies. This finding supports the hypothesis that small and medium-sized manufacturing companies have lower internal capital than large manufacturing companies, are more reliant on outside funding, and are more likely to experience "difficult financing" issues when investing in green technology innovation initiatives.

In the intermediary effect test, since the coefficient of Internet finance and green technology innovation is not significant in the grouping of larger companies, there is no need to conduct the next round of intermediary effect test, and the intermediary effect does not exist. As for the test results of the smaller-scale company subgroup, column (2) shows that the coefficient of Internet finance and financing constraints is significantly negative at the 1% level, and Internet finance can alleviate the financing constraints of smaller-scale manufacturing companies to some extent. In column (3), the coefficients of Internet finance and financing constraints are significant at the 5% and 1% levels, respectively, indicating that the mediating effect of financing constraints is significant and partially mediated in the smaller group of companies. Therefore, it is concluded that the mitigating effect of Internet finance on financing constraints is more significant in SMEs compared to larger companies, which in turn affects the promotion of green technology innovation in SMEs, and Hypothesis 3c is tested. This illustrates the reality that small manufacturing companies have more financial restraints and issues than large manufacturing companies. These funding issues are resolved by traditional financial services, and Internet finance, as an addition to traditional finance, brings up new financing options for these SMEs with "financing difficulties" attributable to its technical advantages, thus resolving their issues.

7 Conclusion

7.1 Research findings

This study examines listed A-share manufacturing firms from 2011 to 2020, empirically tests the relationship between Internet finance and green technology innovation in manufacturing firms, and uses a causal stepwise regression test to examine the mediating role of financing constraints on the role of Internet finance on green technology innovation. It also examines whether the impact of Internet finance on green technology innovation in manufacturing firms is positive or negative.

First, Internet finance can encourage manufacturing firms to innovate in green technology. Internet finance effectively compensates for the lack of traditional finance, expands the range of financial services, provides more flexible financing options, lowers the cost of financing for firms, and increases the effectiveness of resource allocation and risk management, creating a financial environment that supports the development of green manufacturing technologies.

Second, Internet finance can reduce the financial constraints of manufacturing enterprises and, to some extent, solve the problem of difficult financing of green projects, which in turn promotes the ability of manufacturing enterprises to innovate in green technologies. The financial constraints contribute to the intermediate effect of Internet finance on the adoption of green technologies by enterprises. Green innovation projects in manufacturing enterprises can get the funds they need through the many financing channels and diverse financing services offered by the Internet finance system. On the other hand, Internet finance innovates the method of matching the financing needs and financial data of manufacturing enterprises through the use of information technology. Internet finance encourages enterprises to increase their investment, which in turn has a direct positive impact on their green technology innovation by easing the financial constraints faced by manufacturing enterprises.

Third, the impact of Internet finance on green technology innovation among manufacturing firms differs between the more developed eastern regions and the central and western regions. Compared with the developed eastern regions, the impact of Internet finance on the innovation capability of manufacturing enterprises is more significant in the landlocked regions of central and western China. The eastern region of China is more economically developed and has advantages in various factors such as capital and information, and the resources brought by Internet finance can be fully utilized by the manufacturing industry in the transformation process. In addition, the development of Internet finance in the central and western regions is at an early stage of development, and the corresponding facilities and penetration rate in the central and western regions are still very different from those in the eastern regions, which is somewhat disadvantageous in the short term, but with the promotion of Internet finance, the central and western regions will gain more benefits.

Fourth, the degree of regional environmental regulation will affect the contribution of Internet finance to the adoption of green technologies by manufacturing enterprises. The promotion effect of Internet finance on the green technological innovation of enterprises in the regions with a lower degree of environmental regulation is more significant compared with the regions with a higher degree of environmental regulation, because the strong regional environmental regulation weakens the effect of Internet finance on the green technological innovation of manufacturing enterprises.

Fifth, firm size heterogeneity is a determinant of the effect of Internet finance on manufacturing firms' green technological innovation. The promotion of green technological innovation in SMEs is influenced by the fact that Internet finance on financing constraints more in SMEs compared to large enterprises. Small and medium-sized enterprises (SMEs) have less internal capital and lower levels of information transparency than large enterprises, and it is difficult for external investors to effectively evaluate SME investment analysis. As a result, SME green innovation projects face significant financing challenges.

7.2 Policy recommendations

In response to the research findings, this study makes numerous legislative proposals to promote Internet finance as well as green technology innovation in manufacturing companies.

First, promote the growth of online finance. The empirical results show that Internet finance can support the adoption of green technologies in manufacturing firms. Because Internet finance is still at an early stage of growth and offers few goods, it can play only a limited role in encouraging firms to adopt green technologies. To effectively link financial capital and green development, it is critical to advance the development of Internet finance, strengthen policies for financial institutions to support low-carbon development, and innovate and develop financial products such as green finance, green loans, and green bonds.

Second, we should strengthen policy support for green technology innovation. The government should introduce various policies to support green technologies and provide government subsidies for green innovation projects of manufacturing enterprises, especially for small and medium-sized private manufacturing enterprises facing major financing constraints. Second, the Patent Examination Department should introduce the list of green patents as soon as possible, which will also help financial institutions to effectively evaluate green projects.

Third, appropriate Internet finance models should be introduced according to the differences in regional economic development to support the green transformation and upgrading of the manufacturing sector. From the results of the sub-regional estimation, there are some differences in the impact of digital financing on the green technology innovation of manufacturing enterprises in different regions, which is due to the unbalanced development in the eastern and western regions of China. Implementing the same development strategy across the country would lead to a waste of resources, and Internet finance should be developed selectively, and appropriate Internet finance models should be adopted for manufacturing development in different regions to achieve the maximum effect of Internet finance.

7.3 Limitations and future research

First, the company data used in this paper are mainly micro data of listed manufacturing companies with a small sample size, and the impact of Internet companies on green technology innovation of unlisted SMEs is not considered. The number of SMEs in China is huge, and compared with listed companies, the innovative R&D activities of SMEs are more restricted by the shortage of capital. However, due to the undisclosed information of unlisted SMEs, is the data acquisition larger. Therefore, it is not considered in the study.

Second, this study employs a panel model to test the relationship between Internet finance and businesses' adoption of green technology. Future studies may modify this approach by employing threshold models, non-linear smoothed transformation models, etc. to conduct more in-depth analyses of this relationship.

Third, there may be a non-linear relationship between Internet finance and green technology innovation of manufacturing companies, and the promotion effect of Internet finance development on green technology innovation of manufacturing companies is not necessarily steady and durable. Future research should examine the existence of a non-linear relationship between Internet finance and green technology innovation of manufacturing businesses.

Fourth, digitalization has enabled the national economy and microenterprises to change and improve their dynamics. At the policy and practical levels, digital transformation has become an important lever to drive industry optimization and upgrading, and achieve green and high-value development. The contribution of digital technology to green innovation is reflected in the following aspects: first, the effect of knowledge sharing. Enterprise digitalization can realize internal information sharing and knowledge integration to optimize green innovation resources. Second, transaction cost reduction. The development of digital technology can not only reduce the external search, negotiation, negotiation and monitoring costs caused by information asymmetry, but also enable organizational management through information technology to improve the transparency and effectiveness of information, thereby reducing the internal and external transaction costs of enterprises and motivating them to carry out green innovation activities. Third, demand incentive effect. The development of digital technology has stimulated demand for a variety of consumer products and changed the nature of communication between product supply and demand, making it easier to align consumer demand with corporate research and development of green processes. On this basis, the topic of "enterprise digitalization—green innovation performance" needs to be analyzed in depth to clarify the potential mechanism of the influence of digital technology on green innovation and to show the compatible path between enterprise digitalization and green sustainable development.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: (CSMAR) (https://www.gtarsc.com/); (STATISTICAL YEARBOOK OF CHINA) (http://www.stats.gov.cn/).

Author contributions

YY and YL contributed to conception and design of the study. TN organized the database. CG performed the statistical analysis. YL wrote the first draft of the manuscript. YY, YL, TN, and CG wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

This work was supported by the Ningbo Soft Science Project "Research on Mechanism and Path of Green Innovation in Manufacturing Industry under Double Carbon Strategy," under Grant number 2022R020; Longyuan Construction Finance Institute of Ningbo University Project "Research on Impact of Internet finance Development on Development of Construction Industry" under Grant number LYZDA 2002; Zhejiang Philosophy and Social Science Planning Pro-ject "Research on construction mechanism and path of Ecological Civilization Highland in Zhejiang;" Advanced Humanities and Social Sciences Cultivation Project in Ningbo University in 2022 (Pro-phase Project of Cultivation) "Research on Synergistic Effect of Reducing Pollution and Carbon" under Grant number XPYQ22001, Ningbo Philosophical and Social Science Planning "Research on Green Innovation Path of Ningbo Specialized Small Giant Companies under Double Carbon Strategy" under Grant number G2022-2-70, and Ningbo Urban Civilization Research Institute (Preparation) "Investigation and Renovation of Environment and Health Conditions in Ningbo Rural Area" under Grant number CSWM202211.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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