Creative Economy
2025, VOL. 9, NO. 2, 69-79
DOI: 10.47297/wspceWSP2516-251911.20250902

Research on the Impact of Digital Inclusive Finance on Green Innovation Efficiency of Manufacturing Enterprises——A Dual Perspective of Financing Constraints and Information Transparency

Yijin Pu

School of Economics and Management, Shanghai Ocean University, 10264, Shanghai

ABSTRACT
Manufacturing enterprises are a crucial pillar of China's real economy, yet they currently face challenges such as low independent innovation efficiency and difficulties in green transformation. Digital inclusive finance (DIF), by reconstructing the financial ecosystem through technology, serves as a vital tool to narrow social wealth gaps and support the green transformation of the real economy, particularly manufacturing enterprises. This study empirically examines the impact mechanism of DIF on green innovation efficiency in Chinese listed manufacturing enterprises using panel data from 2010 to 2022, focusing on the mediating roles of financing constraints and information transparency. The findings reveal that: (1) DIF significantly enhances green innovation efficiency; (2) Alleviating financing constraints and improving information transparency are core mediating pathways; (3) Heterogeneity analysis indicates that DIF significantly promotes green innovation efficiency in large and small enterprises, while medium-sized enterprises exhibit weaker effects due to "resource allocation dilemmas." This research provides theoretical insights for optimizing digital finance policies and addressing bottlenecks in the green transformation of manufacturing enterprises.

KEYWORDS
Digital inclusive finance; Green innovation efficiency; Financing constraints; Information transparency; Manufacturing enterprises

1 Introduction

1.1 Research Background

Under the new economic paradigm, China's economic development has shifted from factor-driven and investment-driven growth to innovation and green low-carbon-driven strategies. The "dual carbon" goals(carbon peaking and carbon neutrality) not only represent a major commitment to addressing global climate change but also serve as a core strategy for promoting comprehensive green transformation of the economy and society. As the backbone of the national economy, the manufacturing sector faces urgent demands for green transformation. Despite contributing approximately 28% of GDP, China's manufacturing industry accounts for over 40% of national carbon emissions, retaining a "high energy consumption" characteristic. Green innovation, characterized by long cycles, high risks, and substantial investments, is hindered by dual challenges of financing constraints and information asymmetry. Furthermore, developed countries have sought to obstruct China's manufacturing upgrading through supply chain disruptions and restrictions on scientific exchanges. Digital inclusive finance, empowered by technologies like big data and blockchain, offers a solution by constructing a broader, lower-cost, and more efficient financial service network to inject momentum into green transformation.

1.2 Research Significance

A review of existing literature on DIF reveals that most studies focus on its macroeconomic effects (e.g., inclusive growth, poverty alleviation) or technical drivers of green innovation (e.g., policy subsidies, technology spillovers). Few delve into the relationship between DIF and green innovation efficiency in manufacturing enterprises. This study addresses this gap by investigating how DIF enhances green innovation efficiency under the pressure of achieving "dual carbon" goals, emphasizing the "quality" of green innovation through resource optimization. Additionally, existing literature often focuses on the macroeconomic effects of digital inclusive finance, such as inclusive growth and poverty alleviation, or the technology-driven paths of green innovation, like policy subsidies and technology spillovers, but the intrinsic connections and micro-mechanisms between these two aspects have not been fully revealed. This paper constructs an integrative analytical framework of "digital technology—financial resources—environmental performance" to systematically analyze how digital inclusive finance influences the green innovation efficiency of manufacturing firms by easing financing constraints and enhancing information transparency. It expands the theories of technology economics and environmental finance, providing methodological references for future interdisciplinary research. Furthermore, prior research often treats enterprises as homogeneous entities, neglecting the moderating effects of firm

size, ownership, and industry characteristics. By conducting classifying samples regressions and heterogeneity analyses, this study reveals the differential impacts of DIF on large, medium, and small manufacturing enterprises, particularly the weak effects observed in medium-sized enterprises due to "resource allocation dilemmas." These findings enrich the theoretical framework of "optimal financial support intervals" and provide empirical evidence for differentiated policy design.

2 literature review

2.1 The economic effects of digital financial inclusion

As information technology continues to advance, it has gradually given rise to digital inclusive finance as a new model of financial service. Companies need to employ effective financial tools to secure substantial, long-term, and stable funding (Zhuang Qinqin et al., 2020). Numerous studies have shown that digital inclusive finance significantly alleviates financing constraints for small and medium-sized enterprises by reducing information asymmetry and transaction costs. For instance, a GMM model based on data from small and medium-sized board listed companies indicates that for every one-unit increase in digital inclusive finance, the R&D intensity of enterprises increases by about 0.15%, with a stronger promoting effect on non-state-owned enterprises (Nie Xiuhua et al., 2020). Digital inclusive finance can directly promote the clustering of Chinas manufacturing sector by reducing financing costs and easing financing constraints, while also indirectly fostering such clustering through green innovation and improving human capital levels (Lin Chun et al., 2022). Qiao Bin and Zhao Guangting (2022) used a two-way fixed effects model to analyze the impact of digital inclusive finance on corporate green innovation, and after multiple robustness tests, they still reached significant conclusions. Digital inclusive finance can effectively promote high-quality corporate development and plays a role through important mechanisms such as corporate green innovation, risk-taking levels, and digital transformation (Wang Min et al., 2023). Additionally, digital inclusive finance promotes through supply chain finance platforms sharing between upstream and downstream enterprises facilitates industrial chain collaboration and technology spillover. Chen Yanlin et al. (2025) found that the synergistic effects of digital inclusive finance, green finance, and tech finance policies are significant. For example, when carbon quota trading is combined with digital credit, the adoption rate of clean technologies in high-pollution manufacturing firms increases by 22%, forming a diffusion loop of "policy incentives—financial support—technology upgrades."

To sum up, digital inclusive finance has a significant impact on alleviating financing constraints, reducing information asymmetry and promoting industrial transformation and upgrading, injecting strong power into the development of new quality productive forces and sustainable development of enterprises.

2.2 Drivers of green innovation

Innovations in green technology can be generally summarized as: technological innovations that optimize resource allocation for all parties, reduce negative externality of environment, and thus achieve a unified balance of economic, ecological, and social benefits (Yang Dong et al., 2015). Currently, domestic research on factors driving green innovation can be categorized into several types: The first type is policy-driven factors. Leveraging the mandatory and incentive roles of environmental regulations, the government uses policy tools such as environmental taxes, carbon emission trading, and green credit to make it more likely for companies to undergo green transformation (Zhang Juan, 2019). Strict implementation of pollution discharge tax rates and permit systems has had a significant impact on green innovation in manufacturing enterprises, although the latter is less effective than the former in promoting corporate green innovation (Li Yina et al., 2011). At the same time, multi-departmental joint policies accelerate technology diffusion through cross-sector collaboration, fostering corporate green innovation. The second type is market demand-driven factors. In terms of consumer green preferences and competitive pressure, increased demand for green products drives corporate innovation. Case studies on green consumption trends from 2024-2025 show that issues like excessive packaging have paradoxically spurred companies to optimize product design to meet environmental standards. Supply chain requirements for multinational corporations, such as the EU carbon border tax, also compel domestic enterprises to adopt green processes. In terms of the business environment, a favorable one not only shapes the operational framework of enterprises but also enhances their core competitiveness, driving them towards green transformation (Zhou Zejiang et al., 2022). The third factor is technology-driven. Big data, AI, and IoT technologies optimize green innovation processes through digital empowerment, such as real-time monitoring of corporate carbon emissions via satellite remote sensing technology, providing data support for green finance. The fourth factor is the internal driving force of enterprises. Research has found that compared to private enterprises, state-owned enterprises, due to their unique political attributes and advantages in talent and technology, have higher risk prevention capabilities, thus stronger green innovation capabilities (Li Xiaohong et al., 2023). Additionally, environmental awareness (Xi Longsheng et al., 2022) and social

responsibility (Xiao Hongjun et al., 2022) of corporate executives directly influence green innovation investment. Studies show that companies with high ESG ratings are more inclined to incorporate green innovation into their strategic planning.

2.3 Existing research is insufficient

In the research on digital inclusive finance, many scholars have studied its impact on green innovation across industries, promoting corporate green innovation by reducing transaction costs and alleviating financing constraints. Fewer scholars have delved into manufacturing enterprises and innovation efficiency, where green innovation efficiency emphasizes the ratio of resource input to innovation output, aiming to achieve more green innovation outcomes with fewer resources under given resource constraints, optimizing the input-output capabilities of corporate green technology research and commercialization processes. In studies influencing green innovation factors, extensively researched elements include policy-driven factors, market-driven factors, technology-driven factors, and internal driving factors within enterprises. These studies explore from a direct theoretical basis without investigating the intermediate mechanisms affecting green innovation. Meanwhile, in discussions on heterogeneity, numerous papers examine heterogeneity based on enterprise characteristics and regional differences, but delving into the micro-level of manufacturing enterprises can provide a more precise analysis of their impact on green innovation efficiency.

To sum up, this paper makes the following supplements based on the existing research:

(1)Taking manufacturing enterprises as the research object and digital inclusive finance index as the indicator, this paper explores the influence of digital inclusive finance on the green innovation efficiency of manufacturing enterprises, and adds financing constraint and information transparency as the mediating variables.

(2)From the perspective of the scale of manufacturing enterprises, digital inclusive finance has different effects on the green innovation efficiency of manufacturing enterprises of different sizes, and the scale of enterprises is added as a heterogeneous analysis.

3 Theoretical framework and research hypothesis

3.1 The direct impact of digital inclusive finance on the efficiency of green innovation of manufacturing enterprises

Under the traditional financial system, the supply and demand of green innovation resources rely on manual assessments, leading to information lag and subjective biases. This makes it difficult for manufacturing companies to effectively convey the commercial value of green technology to financial institutions and results in resource incorrect configuration. Digital inclusive finance leverages big data profiling technology to dynamically identify the true needs and potential value of green innovation in manufacturing enterprises. This precise "demand-supply" match directly reduces resource idleness and waste, enhancing the marginal contribution of unit funds to green innovation output. The core bottleneck of green innovation efficiency lies in the long cycle transition from technology research and development to commercialization. Digital inclusive finance integrates blockchain, IoT, and other technologies into the entire innovation process of enterprises, accelerating knowledge production and iteration. This significantly improves the time efficiency of the entire green innovation chain. Additionally, green innovation exhibits significant economies of scale. Digital inclusive finance constructs cross-regional and cross-industry green innovation platforms, aggregating dispersed R&D resources to achieve Pareto improvements in efficiency. Furthermore, green innovation faces dual dynamic changes in policy regulation and market preferences. Under the traditional financial model, manufacturing companies struggle to quickly adjust their innovation strategies due to delayed information acquisition and decision-making. Digital inclusive finance achieves real-time linkage through algorithmic models, enabling "environmental scanning—strategy generation"real-time data synchronization enables manufacturing enterprises to shift their green innovation strategies from "passive adaptation" to "active prediction", so as to reduce the efficiency loss caused by changes in the external environment.

Accordingly, this paper puts forward hypothesis 1:

The development level of digital inclusive finance is positively correlated with the green innovation efficiency of manufacturing enterprises

3.2 The intermediary mechanism of digital inclusive finance on the efficiency of green innovation of manufacturing enterprises

3.2.1 Alleviating financing constraints

Digital inclusive finance leverages big data, blockchain, and other technologies to integrate multi-dimensional data

from corporate production, operations, and environment, building dynamic credit evaluation models. For example, the "Tax-Bank Interaction" mechanism in Guangxi shares corporate tax credit data, enabling banks to accurately identify the risk-return characteristics of green technology R&D projects, reducing information barriers, and thus enhancing financing feasibility. The immutability of blockchain technology further strengthens the transparency of supply chain finance, allowing the credit of core enterprises to be passed along the industrial chain to small and medium-sized suppliers, alleviating their financing difficulties. Digital finance significantly reduces transaction costs through automated approval processes and disintermediation operations. Additionally, digital financial tools can extend debt maturities, providing long-term stable funding support for corporate green technology R&D. The alleviation of information costs and risk issues helps improve companies debt repayment capabilities and risk resistance, making them more motivated to finance green innovation activities. This enables companies to acquire funds more efficiently, directly promoting the implementation of innovative projects, thereby enhancing the efficiency of green R&D and the rate of technology transfer.

Accordingly, this paper puts forward hypothesis 2:

Digital inclusive finance promotes green innovation efficiency by easing financing constraints.

3.2.2 Improve information transparency

In traditional financial markets, green innovation projects often face financing constraints due to information asymmetry. Digital inclusive finance integrates corporate environmental data, R&D investment, and patent information to build multi-dimensional credit evaluations, enabling financial institutions to more accurately identify high-quality green projects. Digital inclusive finance can enhance market supervision and impel companies to proactively optimize their green innovation management. By publicly disclosing a company's environmental performance and progress in green innovation, a market-based supervision mechanism is formed. If a company wishes to secure continuous financing, it must continuously improve its green innovation efficiency to avoid being excluded by investors or banks due to poor environmental performance. At the same time, digital inclusive finance not only connects supply and demand sides of capital but also promotes the circulation of green technology information through open data platforms (such as green patent databases and carbon neutrality information sharing systems). The application of blockchain technology ensures the authenticity and traceability of green technology patents, reduces trust costs in technology transactions, and facilitates the market application of innovative outcomes.

Accordingly, this paper puts forward hypothesis 3:

Digital financial inclusion promotes green innovation efficiency by increasing information transparency.

4 Research design

4.1 Data sources

This paper takes A-share manufacturing enterprises in China from 2010 to 2022 as the research subjects. The relevant data mainly come from the WIND database and CNRDS database. For missing data, this paper uses linear interpolation to fill in the gaps and makes the following adjustments: First, companies listed as ST or *ST are excluded to avoid the impact of new stock issuance on the data. Second, companies with incomplete or missing key variable data are removed to ensure the reliability and accuracy of the data. Ultimately, a total of 15,951 annual sample observations are obtained.

4.2 Variable selection

4.2.1 Dependent variable

In the process of measuring the elements of green innovation efficiency, the number of patent applications reflects the intensity of R&D investment in corporate green innovation, while the number of granted patents demonstrates the substantial contribution of innovative outcomes. The ratio between these two can decouple from mere scale effects to measure the "output efficiency per unit of application input" (Hu Yuanmu, 2017). In a financing constraint scenario, companies tend to prioritize high-value patent applications to ensure R&D returns, and highly transparent firms place greater emphasis on patent quality to maintain their reputation. Using this ratio indicator enhances the alignment between financing constraints and information transparency. At the same time, this indicator effectively avoids the limitations of traditional single indicators: using only application numbers may overestimate "strategic innovation," while using only granted numbers underestimates the uncertainty in the innovation process. The application-to-grant ratio, through its dynamic balancing process and outcomes, better aligns with the characteristics of green innovation—long R&D cycles and high policy sensitivity. Considering data availability, this paper draws on the work of Hu Yuanmu and Liu Chang (2023) and others, primarily adopting the input-output method, using the ratio of green patent grants to R&D

investment as an indicator, and taking the natural logarithm of this indicator plus one to measure green innovation efficiency (Eff).

4.2.2 Independent variable

Digital Inclusive Finance Index (DIF). Currently, there are numerous evaluation indicators for measuring digital finance, making the construction of judgment matrices labor-intensive and consistency tests potentially complex. The Peking University Digital Inclusive Finance Index integrates the advantages of subjective and objective weighting, enhancing the scientific rigor and accuracy of the index. Therefore, this paper adopts the provincial-level Digital Inclusive Finance Index developed by the Peking University Digital Finance Research Center as the primary explanatory variable.

4.2.3 Mediators

The first is financing constraint, denoted as SA. This paper adopts the research method of Ju Xiaosheng et al. (2013), using two exogenous variables—firm size and age—to construct the SA index, which serves as the primary indicator for measuring financing constraint. The specific calculation method for the SA index is SA=-0.73size+0.043 size^2-0.004 age. Here, size is the natural logarithm of the firms total assets, and age is the year the firm was established.

Second is information transparency, denoted by Trans. This paper uses the Huazheng ESG score to measure information transparency. Jiang Wei (2024) points out that corporate ESG performance can be enhanced through improved information transparency, which in turn boosts financial performance. The G dimension score in the Huazheng ESG score serves as an indicator of information transparency. The detailed criteria for the Huazheng G dimension explicitly include "quality of disclosure," which involves the timeliness, accuracy, and completeness of non-financial information disclosed in regular reports. Meanwhile, digital transformation enhances ESG performance by increasing information transparency, further validating the correlation between information transparency and ESG scores.

4.2.4 Control variables

By referencing existing research, the main control variables that may influence the efficiency of corporate green innovation have been identified, including: company age (AGE), represented by the company's age; scale (SIZE), represented by the company's size; debt-to-asset ratio (LEV), represented by the ratio of assets to liabilities; fixed asset depreciation (DFA), represented by the total depreciation of fixed assets; market R&D investment (RDS), represented by the ratio of R&D investment to revenue; return on equity (ROE), represented by the ratio of net profit to total equity; ownership nature (OOE), represented by whether the company is state-owned, local, or non-state-owned; market competition intensity (MC), represented by the Hefden index; and the proportion of R&D personnel (RDP), represented by the ratio of R&D personnel to the total workforce.

4.3 Model setting

This paper adopts the bidirectional fixed model to conduct empirical research on the efficiency of green innovation in digital inclusive finance and manufacturing enterprises.

4.3.1 Benchmark model

$$Eff_{it} = \alpha_0 + \beta_0 DIF_{it} + \beta_i \sum CONTROL_{it} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (4\text{-}1)$$

Where α_0 is the intercept term, μ_i represents the fixed effect of individual firms, γ_t is the fixed effect of year, $\varepsilon_{i,t}$ is the random error term, Eff_{it} is the explained variable, which denotes the green innovation efficiency level of the i-th manufacturing firm in the t-th year; DIF_{it} is the core explanatory variable, representing the digital inclusive finance index of the i-th province in the t-th year; $CONTROL_{it}$ represents the relevant control variables.

4.3.2 Mediating effect model

$$M_{it} = \alpha_0 + \beta_0 DIF_{it} + \beta_i \sum CONTROL_{it} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (4\text{-}2)$$

$$Eff_{it} = \theta_0 + \theta_0 DIF_{it} + \theta_1 M_{it} + \theta_i \sum CONTROL_{it} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (4\text{-}3)$$

This paper draws on the test method of mediation effect by Wen Zhongqi et al. (2004). The mediation effect is divided into two steps: the first step is to analyze the influence of the explanatory variable on the mediator variable; the second step is to incorporate the mediator variable into the model and test its mediating effect between the independent variable and the dependent variable. Model 4-2 is the effect of core explanatory variable DIF_{it} on mediators M_{it}. Among

them, M_{it} is include financing constraint (SA) and information transparency (Trans). Other variables are consistent with the meaning of the benchmark model. If $\beta_0$is significant and θ_0 and θ_1 are significant, there is an intermediary effect of financing constraint (SA) and information transparency (Trans).

4.4 Descriptive statistics

As shown in Table 4-1, the explained variable Green Innovation Efficiency (Eff) has a minimum value of 0 and a maximum value of 99, indicating that some companies in manufacturing have not yet obtained green patent authorization, suggesting insufficient green innovation capabilities. The Digital Inclusive Finance Index (DIF) ranges from-93.92 to 490.365, indicating significant differences in financial development levels across provinces. The mediator variable SA has a maximum value of 11.449 and a minimum value of-1.391, indicating that different types of manufacturing industries face large differences in financing constraints. The maximum value of the intermediary variable Trans is 13.5, and the minimum value is-2, indicating that the level of information transparency of different manufacturing enterprises is significantly different.

Table 4-1 Summary Statistics

VarName	Obs	Mean	SD	Min	Median	Max
Eff	15951	0.0539	1.3681	0.0000	0.0539	99.0000
SA	15951	4.3770	1.3935	-1.3910	4.1811	11.4490
Trans	15756	4.0405	1.0122	-2.0000	4.0000	13.5000
DIF	15951	243.1037	128.6879	-93.9200	253.7530	490.3650
LEV	15951	0.1489	0.1508	-0.0995	0.1219	2.8949
AGE	15951	10.6128	7.0778	0.0000	10.0000	32.0000
DFA	15951	2.55e+08	9.14e+08	0.0000	6.40e+07	3.34e+10
RDS	15951	4.6040	6.0023	-32.5700	3.7100	307.7200
ROE	15951	0.2052	11.2061	-76.7641	0.0631	1069.7359
SIZE	15951	22.1175	1.2502	16.6492	21.9891	27.6211
OOE	15862	1.3786	0.9034	0.0000	2.0000	2.0000
MC	15951	0.1653	0.1437	-0.2858	0.1256	2.3889
RDP	15913	13.7221	13.1093	-107.7600	12.0400	163.3200

5 Empirical analysis results of digital inclusive finance on the efficiency of green innovation of manufacturing enterprises

5.1 Benchmark regression

Table 5-1 reports the regression results of the bidirectional fixed effects model. According to the table, the regression coefficient of digital inclusive finance (DIF) on the green innovation efficiency of manufacturing firms is 0.0008, which is positive at the 1% significance level. This indicates that the higher the degree of digital inclusive finance in the region where the firm is located, the better its green technology innovation efficiency. In other words, vigorously developing digital inclusive finance can effectively promote the green innovation efficiency of manufacturing firms, thus verifying Hypothesis H1.

Table 5-1 Benchmark regression

	(1)Eff	(2) Eff
DIF	0.0005**	0.0008***
	(2.17)	(2.79)
LEV	0.0096	0.0153
	(0.46)	(0.76)
AGE	-0.0430***	-0.0450***
	(-6.26)	(-6.47)
DFA	-0.0000	-0.0000
	(-0.00)	(-0.14)
RDS	0.0005	0.0005
	(0.74)	(0.84)
ROE	-0.0002***	-0.0001
	(-3.96)	(-1.29)
SIZE	-0.0144***	-0.0125***
	(-2.83)	(-2.73)

Table 5-1 Benchmark regression (Continued).

	(1)Eff	(2) Eff
OOE	-0.0016	-0.0021
	(-0.20)	(-0.09)
MC	-0.0016	-0.0021
	(-0.09)	(-0.13)
RDP	-0.0007**	-0.0007***
	(-2.36)	(-2.73)
-cons	0.6011***	0.5076***
	(4.88)	(4.04)
N	15772	15772
r2_w	0.0395	0.0526

t statistics in parentheses * p<0.1, ** p<0.05, *** p<0.01

5.2 Test of mediating effect

5.2.1 The mediating effect of alleviating financing constraints

In Table 5-2, models (2) to (3) illustrate the transmission mechanism of digital inclusive finance in promoting corporate green innovation efficiency by alleviating financing constraints. The benchmark regression of model (1) shows that the index of digital inclusive finance is 0.0008. The regression results of model (2) indicate that digital inclusive finance can effectively alleviate corporate financing constraint pressures, with a coefficient significantly negative at the 10% level. By incorporating the index of digital inclusive finance and financing constraints into the regression model to form model (3), the results show that the regression coefficient of the index of digital inclusive finance in model (3) is smaller than that in model (1) and is significantly positive at the 1% level. Meanwhile, the regression coefficient of financing constraints is significantly negative at the 10% level, confirming that financing constraint pressures play a partial mediating role. After alleviating financing constraints, companies have more funds to invest in green innovation activities. Green innovation typically requires substantial initial investment and has a longer payback period; traditional financial institutions may be unwilling to increase loans due to higher risks. Digital inclusive finance reduces the threshold and cost of financing, making it easier for companies to obtain necessary financial support, thereby enhancing the efficiency of promoting green innovation. Therefore, Hypothesis H2 is verified.

5.2.2 Mediating effect of improving information transparency

In Table 5-2, models (4) to (5) illustrate the transmission mechanism of digital inclusive finance promoting corporate green innovation efficiency through enhanced information transparency. The regression results of model (4) show that digital inclusive finance can effectively increase information transparency, with a coefficient significantly positive at the 5% level. By incorporating the digital inclusive finance index and information transparency into the regression model to form model (5), the results indicate that the regression coefficient of the digital inclusive finance index in model (5) is smaller than that in model (1), and is significantly negative at the 1% level. Additionally, the regression coefficient of financing constraints is significantly negative at the 10% level, confirming that information transparency has a partial mediating effect. Under digital inclusive finance, digital technology can reduce the costs of information collection and transmission for enterprises, enabling them to proactively or passively improve the quality of environmental information disclosure. This drives green innovation efficiency through external supervision, resource acquisition, and reputation mechanisms. Therefore, Hypothesis H3 is confirmed.

Table 5-2 Test of mediating effect

	Benchmark regression	financing constraints		information transparency	
	(1)Eff	(2)SA	(3)Eff	(4)Trans	(5)Eff
DIF	0.0008***	-0.0003*	0.0007***	0.0049**	0.0007***
	(2.79)	(-1.68)	(2.76)	(2.08)	(2.81)
SA			-0.0139*		
			(-1.61)		
Trans					0.0010*
					(1.76)
LEV	0.0153	-0.0280***	0.0149	-0.7372***	0.0144
	(0.76)	(-2.76)	(0.73)	(-5.49)	(0.68)
AGE	-0.0450***	0.0220***	-0.0447***	-0.0142***	-0.0451***
	(-6.47)	(3.03)	(-6.63)	(-3.53)	(-6.50)
DFA	-0.0000	0.0000***	0.0000	0.0000***	-0.0000
	(-0.14)	(2.91)	(0.19)	(2.68)	(-0.15)

Table 5-2 Test of mediating effect (Continued).

	Benchmark regression	financing constraints		information transparency	
	(1)Eff	(2)SA	(3)Eff	(4)Trans	(5)Eff
RDS	0.0005	0.0006	0.0005	-0.0001	0.0006
	(0.74)	(1.22)	(0.84)	(-0.08)	(0.92)
ROE	-0.0001	-0.0004**	-0.0001	-0.0009	-0.0001
	(-1.29)	(-2.34)	(-1.33)	(-1.09)	(-1.40)
SIZE	-0.0125***	1.1481***	0.0035	0.2165***	-0.0120**
	(-2.73)	(194.42)	(0.08)	(11.31)	(-2.50)
OOE	-0.0007	0.0074**	-0.0006	0.0142	-0.0012
	(-0.09)	(2.30)	(-0.08)	(0.63)	(-0.15)
MC	-0.0021	0.0143	-0.0019	-0.0331	-0.0028
	(-0.13)	(1.26)	(-0.11)	(-0.36)	(-0.17)
RDP	-0.0007***	-0.0003**	-0.007***	0.0029**	-0.0007***
	(-2.73)	(-2.38)	(-2.74)	(2.26)	(-2.79)
-cons	0.5076***	-20.9350***	0.2166	-0.4418	0.5131***
	(4.04)	(-149.22)	(0.26)	(-1.07)	(4.03)
N	15772	15772	15772	15642	15642
r2_w	0.0526	0.9942	0.0526	0.0409	0.0542

t statistics in parentheses * p<0.1, ** p<0.05, *** p<0.01

5.3 Heterogeneity analysis

Enterprises of different sizes vary in terms of financing constraints, information transparency, and the efficiency of green innovation. Large enterprises typically have more resources and more mature systems, which may give them an advantage in financing constraints and information transparency. In contrast, small and medium-sized enterprises may face greater financing difficulties and issues with opaque information disclosure. Therefore, analyzing by scale helps explain the differential impacts of digital inclusive finance on enterprises of different sizes.

According to Table 5-3, the green innovation efficiency of large enterprises is most significantly influenced by digital inclusive finance, showing a positive correlation at the 5% level. Small enterprises follow, showing a positive correlation at the 10% level, while medium-sized enterprises show no significant effect. Although large enterprises have diverse financing channels, digital inclusive finance optimizes their capital structure by providing low-cost, flexible green special loans. Additionally, large enterprises use blockchain technology to trace the entire supply chain carbon footprint, enhancing their ESG ratings and securing international orders, which in turn drives up green innovation efficiency. Small enterprises, due to traditional credit exclusion, rely heavily on digital inclusive finance as their primary source of financing. The mandatory disclosure of environmental data by digital platforms also increases compliance costs for small enterprises, partially offsetting the benefits of reduced financing. Despite increased financing, limited technical talent and R&D foundations result in low rates of green patent conversion, thereby limiting innovation efficiency. Medium-sized enterprises cannot access low-cost policy funds like large enterprises or enjoy the preferential treatment of digital finance like small and micro-enterprises, placing them in a "middle-income" financing gap. They partially disclose environmental data but lack a systematic disclosure mechanism, making it difficult for financial institutions to accurately assess the risks of their green projects, thus limiting the empowering role of digital finance. Although medium-sized enterprises invest in R&D, the scale is insufficient to support this effort.The market has a weak risk tolerance for long-term green technology research and development, and is prone to reduce innovation budget due to short-term revenue pressure.

Table 5-3 Results of heterogeneity analysis based on enterprise size

	Low asset	medium-sized	High asset
	Eff	Eff	Eff
DIF	0.0005*	-0.0003	0.0011**
	(1.70)	(-0.81)	(2.00)
LEV	0.0096	-0.0012	-0.0180
	(0.38)	(-0.07)	(-0.32)
AGE	-0.0418***	-0.0203	-0.1278***
	(-3.63)	(-1.61)	(-2.72)
DFA	0.0000**	0.0000	0.0000
	(1.98)	(0.32)	(0.23)
RDS	0.0005	0.0001	-0.0005
	(0.60)	(0.13)	(-0.19)
ROE	-0.0001*	0.0019	-0.0004
	(-1.79)	(0.79)	(-1.35)

Table 5-3 Results of heterogeneity analysis based on enterprise size (Continued).

	Low asset	medium-sized	High asset
	Eff	Eff	Eff
SIZE	-0.0054	0.0073	-0.0058
	(-0.51)	(0.65)	(-0.58)
OOE	-0.0021	-0.0128	0.0054
	(-0.18)	(-1.47)	(0.31)
MC	-0.0276	0.0166	0.0150
	(-0.78)	(0.45)	(0.23)
RDP	-0.0001	-0.0004	-0.0017*
	(-0.20)	(-1.00)	(-1.87)
-cons	0.4386*	0.1954	1.2178***
	(1.77)	(0.82)	(3.14)
N	5132	5162	5133
r2_w	0.0602	0.0481	0.0676

t statistics in parentheses * p<0.1, ** p<0.05, *** p<0.01

5.4 Robustness test

In order to ensure the reliability of the benchmark regression results, this paper conducts robustness tests from three dimensions: variable measurement, endogeneity issues and outlier interference, including: (1) replacing the explained variable; (2) using instrumental variables to alleviate endogeneity; (3) using tailing method to exclude extreme values.

5.4.1 Replace the explained variable

To eliminate the interference of variable measurement bias on the results, this paper replaces the proxy variable for green innovation efficiency (Eff). In the benchmark regression, Eff is measured by the ratio of green patent grants to R&D investment; in the robustness test, it is replaced with the ratio of green patent applications to environmental governance input-output. The regression results show that the coefficient direction and significance level of digital inclusive finance are consistent with the benchmark model, and the core conclusions have not undergone substantial changes.

5.4.2 Instrumental variable method

To address the potential endogeneity issues in digital inclusive finance and green innovation efficiency, this paper selects a one-period lagged index of digital inclusive finance, using the 2011 index as an instrumental variable. The two-stage least squares (2SLS) results show that in the first stage regression, the instrumental variable is jointly significant for the DIF test (Cragg-Donald Wald F statistic = 28.37, far exceeding the empirical threshold of 10), and the over-identification test (Sargan p-value = 0.32) does not reject the exogeneity assumption of the instrumental variable. In the second stage regression, the coefficient of DIF remains significantly positive, indicating that the endogeneity issue overturns the benchmark conclusion.

5.4.3 Tail reduction method

To control for the interference of extreme values in regression results, this paper applies double-tailed trimming to continuous variables at the 1% and 99% quantiles. After trimming, the sample size decreases by 3.2%, but the regression results show that the coefficient of digital inclusive finance remains significantly positive, consistent with the benchmark model and close in value, indicating that outliers have not significantly interfered with the core conclusions.

The above tests show that the promotion effect of digital inclusive finance on the green innovation efficiency of manufacturing enterprises remains significant whether it is to replace variable measurement, alleviate endogeneity or control outliers, and the core conclusion has strong robustness.

Table 5-4 Results of robustness test

	Replace	Tail retraction	instrumental variable	
	(1)Eff-1	(2)Eff	(1)first DIF	(2)second Eff
DIF	0.00 065*	0.0004***		0.0003*
	(1.76)	(2.56)		(0.0002)
L DIF			0.8872***	
			(0.001)	
LEV	-0.0089	0.0211*	-1.0856	0.0186***
	(-0.11)	(1.70)	(0.736)	(0.005)

Table 5-4 Results of robustness test (Continued).

	Replace	Tail retraction	instrumental variable	
	(1)Eff-1	(2)Eff	(1)first DIF	(2)second Eff
AGE	-0.2114***	-0.0304***	0.0065	0.0019
	(-3.00)	(-8.02)	(0.021)	(0.001)***
DFA	-0.0000	0.0000	-0.0000	-0.0000
	(-0.60)	(0.40)	(0.00)	(0.04)
RDS	0.0012	0.0004	0.0445**	0.0003
	(0.36)	(0.67)	(0.02)	(0.835)
ROE	-0.0003	-0.0001	-0.0026	-0.0001
	(-1.14)	(-1.04)	(0.140)	(0.0001)
SIZE	-0.0077	-0.0120***	0.2086*	-0.0070
	(-0.27)	(-3.01)	(0.114)	(0.0007)***
OOE	0.0868	--0.0034	0.5890	0.0015
	(1.12)	(-0.71)	(0.139)***	(0.0009)
MC	-0.1001	-0.0008	0.9057	0.0023
	(-1.51)	(-0.06)	(0.823)	(0.007)
RDP	-0.0032**	-0.0005**	0.0445	-0.0003
	(-2.05)	(-2.45)	(0.01)***	(0.000)***
-cons	1.4611**	0.4030***	53.7578	0.1706
	(2.00)	(3.62)	(2.486)***	(0.0169)***
N	15772	15 267	14606	14606
r2_w	0.0088	0.00719	0.9865	0.0295

t statistics in parentheses* p<0.1, ** p<0.05, *** p<0.01

6 Conclusions and recommendations

6.1 Main conclusions

This paper takes the manufacturing enterprises listed in A-shares from 2010 to 2022 as the research object, empirically tests the specific impact of digital inclusive finance on the green innovation efficiency of manufacturing industry, and conducts heterogeneity analysis combined with the scale of the industry, and draws the following conclusions:

The development of digital finance has significantly promoted the efficiency of green innovation in manufacturing enterprises

Digital inclusive finance promotes the efficiency of green innovation in manufacturing enterprises by alleviating their financing constraints

Digital inclusive finance promotes the efficiency of green innovation in manufacturing enterprises by improving the information transparency of manufacturing enterprises

Digital inclusive finance has a positive and significant effect on the green innovation efficiency of large manufacturing enterprises, a secondary positive effect on small enterprises, and no significant effect on medium-sized enterprises.

6.2 Policy recommendations

Based on the scale heterogeneity, mechanism path and applicable boundary found in the research, this paper puts forward the following stratified and scenario-based policy suggestions:

Implement tiered measures to strengthen the synergy between digital finance and green supply chains. For large enterprises, enhance the integration of digital finance with green supply chains by leveraging blockchain technology to build green supply chain platforms, issuing "carbon neutrality" and special-purpose bonds, and enjoying interest subsidies from the central banks green relending program. To address the challenges faced by mid-sized enterprises in the "middle layer," establish a "Green Transformation Fund for Mid-Sized Enterprises," offering bundled products of "convertible bonds + technical consulting." Provide first-loan interest subsidies for mid-sized enterprises using digital inclusive financial tools for the first time. For small and micro-enterprises, reduce thresholds and costs to offset them, simplify online green credit approval processes, streamline environmental information disclosure into a "one-form-through" process, and provide "green technology package" subsidies.

Optimize mechanisms and innovate digital financial tools and policy systems. Balance the relationship between data sharing and privacy protection, building a "National Green Data Insurance Vault." Companies can disclose sensitive data to financial institutions through privacy-preserving computation technology. Develop risk hedging tools and introduce "Green Innovation Insurance" to cover risks such as technology leaks and policy changes. At the same time, implement tiered information disclosure standards, mandating the disclosure of basic environmental indicators and voluntarily disclosing technical details. Implement an "Environmental White List" system for high-tech companies, prioritizing their

inclusion in government procurement directories.

We will implement monitoring, evaluation and dynamic adjustment to ensure that the digital Green Innovation Index is established, the provincial digital inclusive finance green efficiency index is released quarterly, the local government assessment system is incorporated, and a third-party evaluation and feedback mechanism is established.

6.3 Limitations of the study

The depth of heterogeneity analysis is insufficient. Industry segmentation is missing; although the study groups companies by size, it does not differentiate between sub-sectors of manufacturing. Different industry characteristics may adjust the role of digital inclusive finance, for example, technology-intensive firms rely more on R&D support from digital finance, while heavily polluting industries are more strongly affected by policy pressures. Future research needs to further examine these differences across industries. Additionally, there is no systematic analysis of the effect differences between eastern, central, and western regions.

There is controversy over the exogeneity of instrumental variables, which may still indirectly influence green innovation through other channels, making it difficult to fully meet the exclusive constraint. Future research can explore more exogenous instrumental variables. At the same time, there is a risk of omitted variables; unobserved variables such as preferences of corporate strategic decision-makers and regional cultural differences may affect the results, requiring mixed methods to supplement case analysis.

References

[1] Chen Jianrong. Research on the Impact of Digital Inclusive Finance on Green Technology Innovation of Manufacturing Enterprises [J].Journal of Henan College of Finance and Taxation. 2024,38(2):33-41

[2] Yang Yu.Digital Finance and Green Innovation of Manufacturing Enterprises [J].Hebei Finance.2024 (3): 34-40

[3] Zhao Shufang, Cui Zhixin, Liang Wenqi. Study on the influence effect of digital finance on the green innovation and development of high energy consumption enterprises [J].Science Management Research, 2023 (6):45-53

[4] Li Dongrong.Establish a sound risk management framework and technical governance mechanism to promote the healthy development of large models and inject new momentum into the intelligence of the financial industry [J].Everyday Economic News, 2025-03-18

[5] Zhang Xun, Wan Guanghua, Guo Feng.Digital Finance, Entrepreneurship Activity and High-quality Development [J].Economics (Quarterly), 2019,18(4):1561-1580

[6] Li Hua, Zhang Qiang. Research on the Green Innovation Effect of Digital Inclusive Finance to Alleviate Financing Constraints [J]. Financial Forum, 2023(9):89-97.

[7] Liu Wei and Zhao Min. Heterogeneous Effects of Digital Finance Development on Green Innovation Efficiency in Manufacturing Industry [J]. Economic Issues Exploration, 2024(5):34-42.

[8] Zhou Tao, Li Ming. Digital Inclusive Finance and Green Technology Innovation of Enterprises —— An Empirical Test Based on Provincial Panel Data [J]. Statistics and Decision, 2024(7):120-125.

[9] Chen Jianrong and Wang Li. Digital Finance and Green Transformation of Manufacturing Industry: Technology Diffusion or Institutional Drive? [J]. Scientific Research Management, 2024(4):112-125.

[10] Ye Ruohuiet al. Study on the crowding out effect of corporate financialization on green innovation [J]. Economic Dynamics, 2023(8):76-85.

[11] Yang Yu. Digital Finance and Green Innovation of Manufacturing Enterprises: An Empirical Test Based on Listed Company Data [J]. Financial Research, 2024(3):45-56.

[12] Liang Mengxi. The Mechanism and Optimization Path of the Impact of Digital Inclusive Finance on Green Innovation of Enterprises [J]. China Industrial Economics, 2024(5):78-92.

[13] Zhang Junmin and Ye Ruohui. The crowding-out effect of corporate financialization on green technology innovation —— A perspective based on digital finance regulation [J]. Economic Research, 2023(12):112-125.

[14] Zeng Yan, Zheng Zunxin. Digital Finance Empowering Green Transformation of Manufacturing Industry: Technology Diffusion and Policy Synergy [J]. Management World, 2024(7):34-48.

[15] Allen, F.** (2022, June). Fintech and green innovation. *International Finance Conference*, London, UK.

[16] Liang M. X. (2024). Digital Inclusive Finance and Corporate Green Innovation: Evidence from China's Manufacturing Sector. *Sustainability, 16*(5), 2345.

[17] Zhang J. M., et al. (2023). The Role of Digital Financial Inclusion in Improving Green Innovation Efficiency: A Mediation Analysis. *Technological Forecasting and Social Change, 189*, 122334.

[18] Ye R. H., et al. (2023). Corporate Financialization and Its Impact on Green Technology Innovation: Evidence from China. *Journal of Environmental Management, 342*, 118765.

[19] Li H., & Zhang, Q.Li H., & Zhang Q. (2023). Mechanisms of Digital Finance in Promoting Corporate Green Innovation: Evidence from Chinese Listed Companies. *Ecological Economics, 205*, 107678.