



The impact of digital inclusive finance on corporate ESG performance: based on the perspective of corporate green technology innovation

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Abstract

Enterprises are important subjects in the transformation of national green development, while financial support is an important thrust to promote the fulfillment of environmental responsibility. In the dual context of building a digital inclusive financial system and green transformation of corporate production, this paper explores the impact of digital inclusive finance on corporate ESG performance and its mechanism of action through theoretical and empirical analyses using data of Chinese A-share listed enterprises from 2011 to 2020. It is found that the development of digital inclusive finance significantly contributes to the improvement of corporate ESG performance, and the impact of digital inclusive finance on corporate ESG performance has a marginal decreasing effect, while corporate green technology innovation has a marginal increasing effect on corporate ESG performance. The mechanism analysis found that corporate green technology innovation has a mediating effect. The development of digital inclusive finance can enhance the green technology innovation ability of enterprises, and the green technology innovation of enterprises enhances the green sustainability ability of enterprises and improves the ESG performance of corporates. Further research shows that the effects of digital inclusive finance and corporate green technology innovation on corporate ESG performance are industry heterogeneous and pollution degree heterogeneous. How to promote financial services to better promote the combination of corporate green development and fulfillment of social and environmental responsibility is the most direct research implication of this paper.

Keywords Digital inclusive finance · Corporate ESG performance · Green technology innovation

Introduction

Environmental quality is the basis for all kinds of production activities. While the world economies are developing rapidly, the scale of economic growth has intensified environmental pollution and resource consumption. Enterprises, while contributing economic benefits to the country, are also one of the key players in energy consumption and pollution emissions. In China, for example, the CO₂ emissions of China's 100 listed companies in 2021 will be 5.1 billion tons, an increase of 15.3% year-on-year, and the threshold of listed companies' emissions will rise from 6.19 million tons in 2020 to 9.33 million tons, an increase of 50.73%.¹

Driven by the goal of profitability, corporates often ignore the damage to the environment in the production process and disregard their long-term sustainable development for short-term benefits. Therefore, in order to promote the coordinated development of economic and environmental benefits of corporates, the United Nations Principles for Responsible Investment (UNPRI) launched the corporate ESG evaluation system in 2006. The ESG evaluation system has become an important indicator to measure the sustainability of corporates, which is composed of three parts: Environment, Social, and Governance.

Corporate ESG performance requires companies to face society with a more responsible corporate image and take on the important task of national green development and economic transformation, while green development is also a necessary way for companies to achieve sustainable development. The use of carbon offsetting mechanisms to force

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enterprises to undergo green transformation, accelerate green innovation, and reduce pollution emissions through the use of financial instruments was also re-emphasized at the “Stockholm + 50” China country meeting of the United Nations Conference on the Human Environment in April 2022. However, existing studies, both from theoretical and empirical perspectives, have argued that structural contradictions and ownership discrimination in the traditional financial system have exacerbated financial resource mismatch (Song et al. 2020; Yiping and Han 2021). Public goods theory suggests that environmental protection and resource conservation are considered as “public goods” by companies, and companies are more willing to “use” rather than “invest” them for their own development. The externality of environmental responsibility makes it possible for companies to partially or completely avoid environmental responsibility when they face an external financing gap. However, the financial mismatch in the financial market makes it impossible to allocate borrowed funds effectively as a “resource” (Demirguc-Kunt and Klapper 2012). In the absence of financial support, small- and medium-sized enterprises are more likely to choose activities that can bring revenue in the short term (rent-seeking activities) and thus “squeeze out” funds for green innovation R&D (Song et al. 2020; Yiping and Han 2021). This is a key factor that inhibits small- and medium-sized enterprises from achieving green transformation (Genming and Hongxia 2022, Jingjing and Ye 2020).

It is worth noting that the digitalization and informatization of digital inclusive finance corrects the problem of financial mismatch in the traditional financial system (Xiaoge et al. 2021), providing a good opportunity to boost enterprises’ access to financial services and promote their green development. As a new financial tool to support green development and efficient use of resources, digital inclusive finance can more effectively alleviate the problem of information asymmetry between enterprises and financial institutions, and optimize financial services to help enterprises take more environmental responsibility. The digitization of financial services has promoted the development of digital financial platforms represented by digital inclusive finance. Digital inclusive finance provides more convenient and efficient financial services for enterprises and other potential capital demanders through digital intelligent platforms. Financial development theory holds that an effective financial system and financial services can maximize the use of financial resources and promote economic growth. Some enterprises are often excluded from traditional financial services due to their own scale and asset reserves, and the lack of financial assistance for enterprises has a direct impact on the enhancement of their green innovation capability, which affects their fulfillment of environmental responsibility and their overall ESG performance. Therefore, based on previous scholars’ research, this paper explores whether digital inclusive finance can have an impact on the ESG performance

of enterprises? Does the ability of corporate green technology innovation have a mediating effect on corporate ESG performance?

Based on the perspective of corporate green technology innovation, this article investigates the impact of digital inclusive finance on corporate ESG performance. The article argues that digital inclusive finance enhances corporate green technology innovation, which indirectly improves corporate ESG performance through the mediating effect of corporate green technology innovation. The marginal contributions of this paper are (1) analyzed from the micro perspective of enterprises, and the content of this paper provides micro evidence of the impact of digital inclusive finance on enterprise development. The previous studies on the impact of digital inclusive finance on corporate development are mostly focused on business performance, corporate investment efficiency, or corporate exposure to financial exclusion, but there are few micro studies on the impact of digital inclusive finance on corporate ESG performance. (2) Analyzed from the perspective of public goods, the contents explored in this paper provide empirical lessons for digital inclusive finance to enterprises’ green innovation and contribute to sustainable economic development. Resources and environment as public goods, enterprises often neglect their responsibility for the environment out of internal development goals. By studying the impact of digital inclusive finance on corporate ESG performance, this paper analyzes how digital financial services can help enterprises fulfill their environmental responsibilities and promote their green development. (3) Analyzed from the perspective of innovation theory and signaling theory, this study concludes that corporate green technology innovation has a mediating effect. Few studies have explored the impact of corporate green technology innovation on corporate ESG performance. The improvement of corporate green technology innovation can transmit information about corporate green development to financial investors, which can help enterprises to gain more social attention and financial support and improve their ESG performance. Digital inclusive finance can enhance corporates’ green technology innovation ability, and the innovation of corporates’ green technology promotes corporates’ green transformation, helps corporates improve their ESG performance, accelerates corporates’ energy saving and emission reduction, and speeds up the process of green and sustainable development of corporates.

Literature review and research hypotheses

Relevant literature related to the study of this paper includes studies related to the ESG performance of firms, and the impact of digital inclusive finance on the economic effects of micro firms in two directions.

Research related to corporate ESG performance

Corporate ESG performance is a comprehensive evaluation of corporate environmental responsibility (Environment), social responsibility (Social), and corporate internal governance performance (Governance); the emergence of corporate ESG evaluation system breaks the traditional corporate single information disclosure model, but more emphasis on the comprehensive development of enterprises (Wong et al. 2021). The establishment of corporate ESG evaluation indicators is to measure the social, environmental and economic results of corporate production and development. ESG ratings provide a measure of whether a company is practicing high-quality and sustainable development. Enterprise ESG can reflect the efficiency and effectiveness of enterprises in terms of resource utilization, green investment, social responsibility fulfillment, and company management (Kaitao et al. 2023).

- (1) Study of ESG performance measures of companies. Most of the current measures of ESG performance are based on the Bloomberg (Wong et al. 2021, Tamimi and Sebastianelli 2017), Morgan Stanley Capital International (MSCI) (Shanaev and Ghimire 2022; Plastun et al. 2022), and Refinitiv (Martins 2022) frameworks.
- (2) Study the impact results of corporate ESG performance. DasGupta (2022) finds that poor financial performance motivates firms to improve ESG actions by examining multinational firm data. Martins (2022) empirically investigates that emerging market firms adjust their ESG behavior negatively after a competitive shock by using a double-difference approach. In a study by Li et al. (2018), it is shown that poor ESG performance of firms elicits more response from investors. The majority of investors also pay more attention to the green development capability of companies and tend to give more market attention to companies with faster green transition (Bolton and Kacperczyk 2021; Flammer 2021; Stroebel and Wurgler 2021). Zhang et al. (2020) found that two dimensions of corporate environmental and social responsibility in corporate ESG performance have a positive effect on corporate value based on the perspective of Chinese companies.

Digital inclusive finance, corporate green innovation, and corporate ESG performance correlation study

- (1) To study the impact of financial development on corporate ESG. There is little literature on the impact of digital inclusive finance on corporate ESG performance, and the existing literature mostly studies the impact of

financial development on corporate ESG performance. The financial services provided by financial institutions to enterprises are mostly focused on the lending of financial funds. Flammer (2021) argues that green financing services provided by financial institutions have a significant positive effect on firms' environmental performance and business performance. Dziadkowiec and Daszyńska-Żygadło (2021) collected data on 235 ESG performance misconducts of DAX companies and found that financial services institutions reacted more strongly to ESG news published after 2009 during the review process than before, and that issues arising from corporate governance were more likely to reduce the market valuation of companies than problems encountered by firms in assuming environmental and social responsibility. Muyuan and Hong (2019) argue that corporate ESG performance can reduce the cost of financing and thus increase the market value of firms. The effect of corporate environmental responsibility and corporate governance performance on corporate financing structure is greater than that of corporate social responsibility. Christensen et al. (2021) analyze the effect of corporate ESG information disclosure on corporate finance from the perspective of corporate ESG on corporate finance due to the different ESG measurement models. Based on the above theory, this paper proposes the first research hypothesis.

Hypothesis H1: Digital inclusive finance has a positive contribution to enhance corporate ESG performance.

- (2) To study the impact of digital inclusive finance on corporate green technology innovation. FinTech companies, led by the introduction of new forms of finance such as digital inclusive finance, have eased the difficulties of traditional bank financing and broadened the green financing channels of enterprises by means of remote interaction of information during the epidemic (Galema 2020, Gambacorta et al. 2020). Aghion et al. (2012) studied French companies and found that companies subject to financing constraints during the economic recession are more inclined to choose to reduce the share of investment in R&D. Digital inclusive finance (as has been emphasized in Europe and other countries in recent years) is the construction of blockchains to connect local financial institutions to businesses (Aziz and Naima 2021), allowing the financial system to access business information through simpler information gathering and alleviating information asymmetries between lenders and borrowers (Yu et al. 2022). During COVID-19, the development of digital inclusive finance has enhanced the availability of corporate financing (Berg et al. 2020; Jun

et al. 2021), effectively easing the financing constraints faced by enterprises and helping them to innovate in science and technology (Ping and Junxia 2020; Yu et al. 2020; Rosavina et al. 2019). Green technology innovation capability is an important way for companies to develop and fulfill their environmental responsibility (Acemoglu et al. 2012). The research and development of green technology innovation patents has a distorting effect on some companies with weak environmental responsibility, and such corporates are more inclined to invest their limited funds in the production and development of innovation patents (Huang et al. 2019). The development of digital inclusive finance as an important practice of financial inclusion, in the internal perspective of enterprises (Xuanli et al. 2018), digital inclusive finance on the one hand reduces the threshold of financial services and improves the financing efficiency of enterprises (Song et al. 2020). On the other hand, it reduces the cost of green technology innovation for enterprises and enhances their green technology innovation capability (Xin and Ying 2021). From a business external perspective, the development of digital inclusive finance enhances inclusive urban growth and raises the income level of residents (Taizeng and Zhigao 2022). The increase of residents' income will strengthen the individual's pursuit of a better society and happy life, and the stronger the residents' demand for green development (Zhiqing and Hui 2021). Nguyen et al. (2020) argue that the increase in income of the population will expand its demand effect for environmental optimization and thus increase the demand for green products. Driven by the benefits of green demand, companies' willingness to engage in green technology innovation will also increase (Jing et al. 2021). Based on the above theory, this paper proposes the second research hypothesis.

Hypothesis H2: Digital inclusive finance can enhance the innovation capability of firms in green technology.

- (3) Research on digital inclusive finance, corporate green technology innovation, and corporate ESG performance. Few articles have studied the relationship between digital inclusive finance, corporate green technology innovation, and corporate ESG performance. A review of the existing articles reveals that digital inclusive finance can create synergy with the green finance policies proposed by the government (Jia and Jingbo 2020). By getting rid of the shackles of traditional business outlets, digital inclusive finance can provide more efficient financial services and lower cost financing funds for low-carbon development of enterprises. By combining with government subsidies for

corporate green development and lowering loan taxes and fees, digital inclusive finance directs funds to better flow to green innovative corporates and enterprises with real financing difficulties in green transformation (Shen et al. 2019). On the one hand, the innovation of green technology of enterprises can reduce the pollution of the environment and fulfill the environmental responsibility of enterprises, on the other hand, the green innovation of enterprises is also responsible for the society and the internal staff of corporates (Long et al. 2023). Pedersen et al. (2021) argue that the fulfillment of environmental and social responsibility by corporates increases the uncertainty of future profit forecasts, but at the same time brings higher investor demand and market value to companies, and investors will pay more attention to corporate green technology innovation activities. Chouaibi et al. (2021) found through empirical analysis of UK and German firm data that the better the ESG performance of the firm, the more the firm's ability to innovate in green technology is enhanced. Green technology innovation by corporates can attract more financial investors and help corporates achieve long-term sustainability (Zhang et al. 2022). By improving the efficiency of the corporate's treatment of pollutants, launching green products, attracting potential consumers (Wang et al. 2022), and improving the satisfaction of society and internal members of the corporate (Wang and Sun 2022; Niu et al. 2022) ultimately improve the company's overall ESG level. Based on the above theory, this paper proposes a third research hypothesis.

Hypothesis H3: Corporate green technology innovation has a mediating effect, and digital inclusive finance can improve corporate ESG performance by enhancing corporate green technology innovation capabilities.

Model setup and data

Model setup

To test the aggregate effect of digital inclusive finance on corporate ESG performance, the following benchmark regression model is constructed in this paper. As shown in Eq. (1).

$$ESG_{i,t} = \alpha_0 + \alpha_1 Index_{i,t} + \alpha_2 X_{1i,t} + \alpha_3 X_{2i,t} + \mu_i + \delta_i + \varepsilon_{i,t} \quad (1)$$

where i, t denote firm and year, ESG is the ESG performance of the corporate, Index is the total digital inclusive finance index, X_1 is the three segmentation indicators of digital inclusive finance (breadth of coverage, depth of use and digitalization of digital inclusive finance), X_2 is a set of control

variables, μ_i and δ_i are fixed effects controlling for firm and year, ε is the random error term, α_0 is the intercept, and α_{1-3} is the regression coefficient of each variable.

Furthermore, in order to explore whether there is a mechanism of action between corporate green technology innovation in digital inclusive finance and corporate ESG performance, a mediating effect model is constructed to test on the basis of Eq. (1). The test steps are as follows: First, we verify whether the regression coefficient α_1 of digital inclusive finance (Index) on corporate ESG performance (ESG) in Eq. (1) is significant. On the basis of significance, the regression equations of corporate green technology innovation (Green) on digital inclusive finance (Index), and digital inclusive finance (Index), corporate green technology innovation (Green), and corporate ESG performance (ESG) are constructed respectively. Based on the positivity and significance of the regression coefficients of $\beta_1, \gamma_1, \gamma_2$ in the model, we determine whether there is a mediating effect of corporate green technology innovation in digital inclusive finance and corporate ESG performance. As shown in Eq. (2) and Eq. (3), the mediating effect model is constructed as follows.

$$\text{Green}_{i,t} = \beta_0 + \beta_1 \text{Index}_{i,t} + \beta_2 X_{i,t} + \mu_i + \delta_i + \varepsilon_{i,t} \quad (2)$$

$$\text{ESG}_{i,t} = \gamma_0 + \gamma_1 \text{Index}_{i,t} + \gamma_2 \text{Green}_{i,t} + \gamma_3 X_{i,t} + \mu_i + \delta_i + \varepsilon_{i,t} \quad (3)$$

In order to conduct robustness tests on the one hand, and to examine whether the impact of corporate green technology innovation on corporate ESG performance has a marginal effect on the other hand, in the context of digital inclusive finance, this paper tests this by using a panel quantile model under fixed effects. The panel quantile regression model is used to analyze whether the dependent variable has marginal utility by examining the change in regression coefficients of the dependent variable at different quantile points. In Eq. (4), ESG_{it} denotes the ESG performance of the firm at time t in the i cross-section, the explanatory variables are digital inclusive finance (Index), and firm green technological innovation (Green), X_{it} is the control variable, β_τ is the regression coefficient of the variable, μ_i and δ_i are the fixed effects of the control firm and year, and ε is the random error term. The specific form of the model controlling for fixed effects is shown in Eq. (4).

$$\text{ESG}_{it}^{(\tau)}(\tau_j | x_{it}) = \beta_0 + \beta_{\tau 1} \text{Index}_{it}^T + \beta_{\tau 2} \text{Green}_{it}^T + \beta_{\tau 3} X_{it}^T + \mu_i + \delta_i + \varepsilon_{i,t} \quad (4)$$

Data sources and variable measures

Data sources

In this paper, we select the sample data of domestic listed companies in China A-share market from 2011 to 2020. And the following operations are performed on the data:

- (1) exclude the samples of ST and PT during 2011–2020;
- (2) exclude the samples with too many missing values;
- (3) exclude the samples of financial industry and real estate category;
- (4) winsorize the continuous observed variables in the sample with 1% or lower tail shrinkage, and finally obtain the panel data of 811 companies. In this paper, the data related to corporate finance are obtained from China CSMAR database, the data of corporate green technology innovation are obtained from Wind database, and the indicators of corporate ESG performance rating are obtained from Bloomberg ESG database. The indicators related to digital inclusive finance are obtained from the Digital Inclusive Finance Index 2011–2020 published by the Digital Inclusive Finance Research Center of Peking University, China.

Variable measures

(1) Explained variables

Corporate ESG performance (ESG). Bloomberg's launch of the Corporate ESG Rating System provides a complete and transparent scoring system with data support. Bloomberg's own quantitative model uses sustainability and industry frameworks, analysis and research to reduce noise, standardize data, and address scale bias and under-disclosure. Bloomberg Corporate ESG Performance measures corporate ESG performance in terms of corporate environmental responsibility (CEP), social responsibility performance (CSP), and corporate governance performance (CGP), respectively. In this paper, the Bloomberg ESG scoring system is used to measure corporate ESG performance. The three indicators of corporate environmental responsibility (CEP), social responsibility performance (CSP), and corporate governance performance (CGP) are also selected as explanatory variables for the study. The specific indicators are shown in Table 1.

(2) Explanatory variables

To ensure the scientific validity of studying the impact of digital inclusive finance on corporate ESG performance, this paper draws on relevant studies on digital inclusive finance and selects the total indicators of digital inclusive finance (Index), breadth of coverage (Breadth), depth of use (Depth), and digitalization (Digital) in the first-level indicators as the main explanatory variables (Feng et al. 2020; Jiayu et al. 2020).

In this paper, corporate green technology innovation (Green) is selected as a mediating variable. This paper argues that the development of digital inclusive finance can provide new digital financing channels for enterprises and provide new path options for enterprises to make financing loans. By alleviating the financing constraints

Table 1 Corporate ESG performance indicators

Corporate ESG performance	Comprehensive index	Segmented metrics
Corporate environmental responsibility	Overall environmental risk exposure level	Industry environmental risk exposure level Degree of corporate environmental risk exposure
	Level and quality of environmental	Information disclosure accessibility, availability, and reliability of environmental information
	Environmental risk management performance (positive situation)	Pollutant emissions Energy consumption index Carbon emission intensity
	Environmental risk management performance (negative situation)	Energy saving and efficiency Green business development status Green R&D and investment status
Corporate social responsibility	Shareholders	Shareholder return, small- and medium-sized shareholder return
	Employee	Employee treatment, safety, etc
	Customers and consumers	Product and service quality, privacy, and security
	Upstream and downstream relations, creditors and peers	Debt and contract default, fair competition, etc
	Government and the public	Employment, public welfare spending, etc
	Macroeconomic and financial markets	Economic development and transformation, economic and financial risks, etc
Corporate governance performance	Corporate management strategy	Corporate management strategy Risk management strategy
	Board governance	Board structure, percentage of independent directors, etc
	Corporate governance results	Return on capital, etc
	Abnormalities in corporate governance results	Affiliated transactions, executive turnover rate, etc
	Corporate governance supervision	Role of supervisory board, violations, etc
	Corporate governance transparency and information disclosure	Information disclosure mechanism Compulsory disclosure Voluntary disclosure Information disclosure quality

that enterprises may face increases enterprises' investment in green technology, enhances enterprises' attention to their own green development, and improves their green technology innovation ability. The improvement of corporates' green technology innovation ability can help corporates better fulfill their corporate environmental and social responsibilities and help improve their ESG performance. This paper measures corporate green technology innovation by constructing corporate green patent knowledge breadth indexes by adopting the number of corporate patent applications for technological inventions in pollution management and green applications. In this paper, we select the total number of alternative energy novelty licenses, transportation novelty licenses, energy-saving novelty licenses, waste management novelty licenses, agriculture and forestry management novelty licenses, administrative and regulatory design novelty licenses, nuclear power generation novelty licenses, green invention patent applications, and green utility model patent applications as the width range of corporate green technology innovation patent knowledge by screening corporate patent

applications. On this basis, the total sum of corporate green technology innovation patents is logarized by adding 1 with the corporate patent information provided by Wind database.

(3) Control variables

Referring to previous scholars' studies (Xin and Ying 2021; Longsheng and Hui 2022), this paper selects firm size (Size), firm return on net assets (ROE), firm age (Age), firm location financial development level (Findev), and government support (Gov) as control variables. The specific names, meanings, and descriptions of each variable are shown in Table 2.

Descriptive statistics

Table 3 shows the descriptive statistics for each variable of the sample. The mean value of corporate ESG performance is 20.621, with a standard deviation of 7.033, a minimum value of 1.240, and a maximum value of 9, indicating that

Table 2 Variable definition

Variable category	Variable name	Variable meaning	Variable description
Explained variables	ESG	Corporate environmental, social responsibility and corporate governance composite	Bloomberg ESG Rating System
	CEP	Corporate environmental performance score	Bloomberg CEP Rating System
	CSP	Corporate social performance score	Bloomberg CSP Rating System
	CGP	Corporate governance performance score	Bloomberg CGP Rating System
Explanatory variables	Index	Total digital inclusive finance indicators	Compiled from the logarithm of digital inclusive finance segments
	Breadth	Breadth of digital inclusive financial coverage	Logarithm of the degree of account coverage used
	Depth	Depth of digital inclusive finance usage	Logarithm based on a combination of payments, credit, investment, credit services, and money funds
	Digital	The degree of digitalization of digital inclusive finance	Logarithm based on the combination of digital payment and lending rates
Intermediary variable	Green	Green technology innovation capability of corporates	The total number of green innovation patents of corporates plus one is taken as a logarithm
Instrumental variable	Int	The degree of Internet access	The amount of Internet broadband access in each province in China
Control variable	Size	Size	Natural logarithm of annual total assets
	ROE	Return on net assets	Net profit/average balance of shareholders' equity
	Age	Year of company establishment	(Current year – year of company establishment + 1) logarithmically
	Findev	Financial development level	Financial institutions deposit and loan balance/GDP
	Gov	Government support	Financial support for corporate environmental subsidies/total fiscal expenditure

there is variability in the ESG performance of different corporates. The mean value of digital inclusive finance is 5.322, the standard deviation is 0.612, the minimum value is 2.786, and the maximum value is 6.380, which indicates that there are differences in the development of digital inclusive finance in different regions of China, but comparing the mean value and standard deviation, we can find that the overall level is in the middle to upper level. The mean value of corporate green technology innovation is 0.584, the standard deviation is 1.134, the minimum value is 0, and the maximum value is 7.378, which indicates that there are large differences between corporates in green technology innovation. Analysis of the mean value and standard deviation reveals that most corporates in the sample may have neglected corporate green technology innovation in their development.

Impact of digital inclusive finance on corporate ESG performance

Baseline regression results

Table 4 presents the results of the benchmark regression of digital inclusive finance on corporate ESG performance under fixed effects. The regression results of model 1 show

that the total index of digital inclusive finance has a significant positive impact on corporate ESG performance (regression coefficient of 1.168). Models 2 to 4 report the regression results on the impact of three sub-dimensions of digital inclusive finance (breadth of coverage, depth of use,

Table 3 Descriptive statistics

Variable name	Observations	Mean	Standard deviation	Minimum	Maximum
ESG	8110	20.621	7.033	1.240	64.115
CEP	8110	10.806	7.996	0.775	65.625
CSP	8110	23.835	9.791	3.509	77.193
CGP	8110	44.908	5.302	3.571	64.286
Index	8110	5.322	0.612	2.786	6.380
Breadth	8110	5.217	0.695	0.673	6.880
Depth	8110	5.337	0.570	1.911	6.743
Digital	8110	5.499	0.768	2.026	8.141
Green	8110	0.584	1.134	0	7.378
Int	8110	0.654	0.582	0.332	0.889
Size	8110	22.974	1.436	19.552	48.310
ROE	8110	0.080	0.148	-1.914	1.063
Age	8110	2.852	0.368	1.386	3.584
Findev	8110	3.314	1.147	1.674	7.552
Gov	8110	0.297	0.212	0.120	1.354

Table 4 Benchmarking the return of digital inclusive finance to corporate ESG

Variable name	ESG (Model 1)	ESG (Model 2)	ESG (Model 3)	ESG (Model 4)
Index	1.168*** (0.139)			
Breadth		0.756*** (0.116)		
Depth			1.368*** (0.149)	
Digital				0.847*** (0.078)
Size	0.823*** (0.082)	0.840*** (0.082)	0.851*** (0.081)	1.078*** (0.072)
ROE	1.109*** (0.350)	1.037*** (0.350)	1.101*** (0.349)	0.967*** (0.355)
Age	5.483*** (0.455)	6.393*** (0.427)	5.221*** (0.452)	4.950*** (0.312)
Findev	5.273*** (1.457)	5.297*** (1.460)	5.264*** (1.455)	2.951*** (1.341)
Gov	1.871*** (0.251)	1.932*** (0.253)	1.821*** (0.251)	1.206*** (0.071)
Fixed effects	Yes	Yes	Yes	Yes
R ²	0.644	0.632	0.671	0.634

*, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard deviations are in parentheses. Each regression process in the table controls for both firm fixed effects and time fixed effects. Same as in the following tables

and digitization of digital inclusive finance) on corporate ESG performance, respectively. The regression results show that the breadth of coverage, depth of use, and digitization of digital inclusive finance significantly improve the ESG performance of firms at the 1% confidence level. In terms of the degree of influence of the three, the depth of use of digital inclusive finance has the most significant impact on ESG performance (regression coefficient of 1.368, while the regression coefficients of breadth of coverage and digitalization are 0.756 and 0.847, respectively). Therefore, research hypothesis 1 is verified, indicating that the development of digital inclusive finance helps to improve the ESG performance of corporates, and the depth of digital inclusive finance usage has the most significant positive effect on the ESG performance of corporates.

Table 5 presents the regression results of the three composite indicators of digital inclusive finance on corporate ESG performance under fixed effects. The regression results from models 1 to 3 show that digital inclusive finance has a significant positive impact on corporate environmental responsibility, social responsibility performance, and corporate governance performance at the 1% level. Comparing the regression coefficients of the three, it can be found that digital inclusive finance has the most significant impact on corporate social responsibility performance (regression

coefficient of 1.978), followed by corporate environmental responsibility (regression coefficient of 0.970), and the weakest impact on corporate governance performance (regression coefficient of 0.545). The development of digital inclusive finance can help corporates cope with the financial risks they may encounter in the transformation of economic development, and help them obtain timely financing loans through digital financial platforms. At the same time, it is undeniable that the emergence of digital inclusive finance has an important role in the enhancement of corporate environmental responsibility. By optimizing the financial structure through digital inclusive finance and helping corporates to obtain financial support, corporates can use more available borrowing funds for the treatment of pollutants in the production process and emission reduction and energy saving, thus helping corporates to develop green.

Intermediary effect analysis

To further investigate the mechanism of digital inclusive finance to enhance corporate ESG performance, this paper tests the mechanism of mediating effect by selecting corporate green technology innovation as a mediating variable. This paper argues that the development of digital inclusive finance helps corporates use more available funds for green technology research and development while alleviating their financing constraints. The improvement of corporates’ green technology innovation capability can in turn help them better fulfill their environmental responsibilities, thus improving their ESG performance. Corporates are one of the most important subjects to materialize green technology innovation, and promoting green technology innovation can help corporates achieve sustainable green development. As a means for corporates to fulfill their environmental

Table 5 Impact of digital inclusive finance on corporate ESG performance segmentation dimensions

Variable name	CEP (Model 1)	CSP (Model 2)	CGP (Model 3)
Index	0.970*** (0.171)	1.978*** (0.190)	0.545*** (0.095)
Size	1.638*** (0.125)	1.427*** (0.114)	0.643*** (0.061)
ROE	1.213** (0.532)	0.586 (0.549)	0.213 (0.272)
Age	3.387*** (0.497)	3.199*** (0.558)	2.088*** (0.316)
Findev	6.734*** (1.998)	3.621*** (0.524)	1.581*** (0.267)
Gov	2.541*** (0.441)	2.103*** (0.342)	2.043*** (0.373)
Fixed effects	Yes	Yes	Yes
R ²	0.655	0.512	0.564

Table 6 Regression results of digital inclusive finance, corporate green technology innovation, and corporate ESG performance

Variable name	ESG (Model 1)	Green (Model 2)	ESG (Model 3)
Index	1.168*** (0.139)	0.112*** (0.021)	1.146*** (0.139)
Green			0.194*** (0.757)
Size	0.823*** (0.082)	0.025** (0.013)	0.818*** (0.082)
ROE	1.109*** (0.350)	0.027*** (0.054)	1.104*** (0.350)
Age	5.483*** (0.455)	0.289*** (0.070)	5.539*** (0.455)
Findev	5.273*** (1.457)	0.492*** (0.806)	5.288*** (1.456)
Gov	1.871*** (0.251)	0.076** (0.225)	0.563*** (0.162)
Fixed effects	Yes	Yes	Yes
R ²	0.644	0.539	0.574
Sobel test		0.057*** (0.020)	

responsibilities and reduce environmental pollution, green technology innovation is characterized by high costs, slow results, and high risks. The increase in residents' income and the rise in the overall welfare level of cities brought about by the development of digital inclusive finance has increased the demand for green development of corporates, and corporates are bound to increase their investment in green technology innovation in order to improve their own business performance and social recognition. At the same time, the digital financial platform launched by Digital Inclusive Finance can provide efficient and low-cost services for corporates financing, help corporates enhance their green technology innovation capabilities, and thus support them to contribute to the green sustainability of the whole society and improve their overall ESG performance.

Table 6 reports the regression results of the mediating effects of digital inclusive finance, corporate green technology innovation, and corporate ESG performance under fixed effects. In model 1, digital inclusive finance significantly enhances corporate ESG performance. In model 2, the development of digital inclusive finance has a significant positive effect on corporate green technology innovation at the 1% level. The regression results of model 3 report that the regression coefficient of digital inclusive finance on corporate ESG performance remains significantly positive after adding corporate green technology innovation as a mediating variable, indicating that it has a significant contributing effect and that corporate green technology innovation also significantly enhances corporate ESG performance. In the regression test of model 3, the Sobel test is significantly

positive at the 1% level, indicating that corporate green technology innovation has a positive mediating effect, and the coefficients of digital inclusive finance in both model 1 and model 2 are significant, indicating that corporate green technology innovation has a partial mediating effect, thus proving that hypotheses 2 and 3 are valid.

Heterogeneity test

This paper further investigates the impact of digital inclusive finance on corporate ESG performance by enhancing corporate green technology innovation through heterogeneity testing. First, the sample is divided into manufacturing, business services, scientific research, information and transportation, and water, environment, and public services by industry type to explore whether there is industry heterogeneity in the effects of digital inclusive finance and corporate green technology innovation on corporate ESG performance. By comparing the regression coefficients of digital inclusive finance and corporate green technology innovation in five industries, we analyze the industry differences of digital inclusive finance and corporate green technology innovation on corporate ESG performance. Secondly, the industry types are divided into heavily polluting and non-heavily polluting corporates according to their pollution levels, by comparing the effects of digital inclusive finance and corporate green technology innovation on their ESG performance under a sample of corporates with different pollution levels.

- (1) The impact of digital inclusive finance and corporate green technology innovation on corporate ESG performance is industry heterogeneous. The heterogeneity of industry types affects to some extent the efficiency of the transformation of digital inclusive finance support, green technology innovation on corporate environmental, and social performance. The heterogeneity of inputs and expected outputs of pollutants and renewable waste treatment in different industries affects both digital inclusive finance and green technology innovation by industry. Table 7 reports the regression results of digital inclusive finance, corporate green technology innovation, and ESG performance of firms in different industries under fixed effects. In the report, columns 1 to 5 report the regression results of digital inclusive finance and corporate green technology innovation on the ESG performance of firms in five industries: manufacturing, business services, scientific research, information and transportation, and water, environment, and public services, respectively. Among them, the regression coefficients of digital inclusive finance and corporate green technology innovation both have a significant positive contribution to corporate ESG performance. Comparing the regression coefficients of

Table 7 An examination of industry heterogeneity of digital inclusive finance on corporate ESG performance

Variable name	ESG (Manufacturing industry)	ESG (Business services industry)	ESG (Scientific research industry)	ESG (Information and transportation industry)	ESG (Water environment and public services industry)
Index	1.591*** (0.261)	0.994*** (0.251)	1.136*** (0.223)	1.020*** (0.236)	1.083*** (0.239)
Green	0.902* (0.182)	0.305*** (0.172)	0.670*** (0.161)	0.878*** (0.179)	0.999*** (0.165)
Control variable	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes
R ²	0.616	0.626	0.626	0.625	0.686

digital inclusive finance, it is found that digital inclusive finance has the most significant effect on improving ESG performance of manufacturing type firms (coefficient of 1.591), while it has the weakest effect on improving ESG performance of business service type firms (0.994). Comparing the regression coefficients of corporate green technology innovation, it is found that corporate green technology innovation has the most significant effect on the ESG performance of water environment and public service type companies (coefficient of 0.999). The coefficient is 0.305. In general, the improvement of digital inclusive finance and green technology innovation of corporates has a significant effect on the ESG performance of corporates in manufacturing, water environment, and public services. The possible reason for this is that manufacturing and water environment and public service industries firstly have the resource element of R&D in science and technology innovation and have stronger innovation ability compared to other industries. Secondly, manufacturing and water and environmental management are more likely to produce pollutants in the production process, which has a greater impact on the environment, and these companies have a greater need for sustainable science and technology. High-polluting enterprises can transform green production and resource conservation into environmental performance through green technology innovation, and then fulfill their environmental and social responsibilities.

- (2) The impact of digital inclusive finance, corporate green technology innovation on corporate ESG performance has pollution-type heterogeneity. Table 8 reports the regression results of digital inclusive finance, corporate green technology innovation, and ESG performance of firms with different pollution levels under fixed effects. Columns 1 and 2 in Table 8 report the regression results related to the ESG performance of firms in the heavy pollution category and non-heavy pollution category, respectively. As shown in Table 8, digital inclusive finance and corporate green technology innovation both

significantly enhance the ESG performance of firms with different pollution levels at the 1% level. By comparing the regression results of ESG performance of corporates of two pollution types, it is found that digital inclusive finance and corporate green technology innovation have the most significant effects on ESG performance of corporates with heavy pollution types (regression coefficients of 2.797 and 1.327, respectively). The effects of digital inclusive finance and corporate green technology innovation on ESG performance of non-heavily polluting types of firms are weaker (regression coefficients of 2.367 and 0.921, respectively). Enterprises of different pollution types have different demand effects on corporate green technology innovation due to the different volume of pollutant emissions and treatment. Compared with non-heavily polluting corporates, heavily polluting corporates have a greater demand effect on green technology innovation due to the constraints of government environmental policies and corporates' own environmental and social responsibilities. Accordingly, the more cost pressure they face for green technology innovation, the more obvious the financing gap is. Heavy polluters need more financial support to help them carry out research and development of green innovation. Digital inclusive finance

Table 8 A heterogeneity test of the degree of pollution of digital inclusive finance on corporate ESG performance

Variable name	ESG (Heavy pollution corporates)	ESG (Non-heavily polluting corporates)
Index	2.797*** (0.946)	2.367*** (0.921)
Green	1.327*** (0.278)	0.925** (0.440)
Control variable	Yes	Yes
Fixed effects	Yes	Yes
R ²	0.650	0.614

optimizes corporates' access to financial information and enhances the efficiency of access to financial services. Through digital information and digital financial platform to optimize the financial investment behavior of corporates, thus, the impact on heavy polluting corporates to carry out green technology innovation and improve their ESG performance occupation is more significant.

Endogeneity problem and robustness test

Endogeneity problem

This paper uses the instrumental variables approach to deal with the endogeneity issues that arise in the model. This paper uses the penetration of Internet access (Int) in different provinces of China as an instrumental variable. Model 1 of Table 9 shows the regression results of the impact of digital inclusive finance and corporate green technology innovation on corporate ESG performance after using instrumental variables to address the endogeneity problem. Among them, the effect of instrumental variables on corporate ESG performance is significantly positive, while the positive and negative coefficients of the effect of digital inclusive finance on corporate ESG performance do not change after adding further instrumental variables, indicating that after solving part of the endogeneity problem, corporate green technology innovation can still play a mediating role and digital inclusive finance can still improve corporate ESG performance.

Robustness test

To ensure the scientific validity of the regression results, this paper performs robustness tests on the basis of Eqs. 3 and 4.

Robustness tests are conducted by replacing the model. The fixed-effects model is replaced with the panel quantile model in the fixed-effects model, and the robustness test is conducted by changing the estimated model. The results are shown in models 2 to 4 of Table 9, where models 2 to 4 represent the effects of the independent variables on the conditional distribution of the dependent variable at the 0.25, 0.5, and 0.75 quartiles, respectively. The regression results show that the positive and negative effects of digital inclusive finance and corporate green technology innovation on corporate ESG performance do not change after changing the regression models, and the conclusions drawn in the previous study still hold. Moreover, in the panel quantile regression, by comparing the regression coefficients at different quantile points, it can be found that the regression coefficient of digital inclusive finance on corporate ESG performance becomes smaller and smaller (the regression

Table 9 Endogeneity problem and robustness test

Variable name	Endogeneity problem ESG (Model 1)	Robustness test		
		ESG (Model 2)	ESG (Model 3)	ESG (Model 4)
Index	0.826*** (0.206)	1.690*** (0.155)	1.223*** (0.154)	1.004*** (0.177)
Green	0.683*** (0.051)	0.467*** (0.075)	0.590*** (0.071)	0.847*** (0.129)
Control variable	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
R ²	0.906	0.612	0.611	0.615
Int	0.046*** (0.018)			
Weak instrumental variable test	0.005*** [35.822]			

*, **, and *** denote significant levels at 10%, 5%, and 1% confidence intervals, respectively; those marked with * are regression coefficients; [] denotes the *F*-value of the weak instrumental test

coefficient decreases from 1.690 to 1.223 and then to 1.004), indicating that there is a marginal decreasing utility of the development of digital inclusive finance on corporate ESG performance. Meanwhile, comparing the regression coefficients of corporate green technology innovation can be found (the regression coefficient increases from 0.467 to 0.590 to 0.847), which indicates that there is a marginal increasing effect of corporate green technology innovation on corporate ESG performance because of its time lag.

The results of the robustness test indicate that the conclusions drawn in this paper in the above study are robust, reaffirming the hypotheses presented in the second part of this paper.

Research conclusion and policy recommendations

Research conclusion

Based on financial development theory and endogenous growth theory, this paper explains the relationship between digital inclusive finance, corporate green technology innovation, and corporate ESG performance from both theoretical and empirical analyses and tests the related hypotheses based on Chinese sample data. The study finds that (1) in general, the development of digital inclusive finance has a significant contribution to the improvement of corporate ESG performance. From the segmentation dimensions of digital inclusive finance, the depth of digital inclusive finance usage has the most significant impact on corporate ESG performance, while the breadth of digital inclusive

finance coverage has a weaker impact on corporate ESG performance. From the segmented dimensions of corporate ESG performance, digital inclusive finance has the most significant impact on corporate social responsibility performance, and also has a significant contribution to the fulfillment of corporate environmental responsibility. (2) Corporate green technology innovation has a mediating effect. The development of digital inclusive finance can enhance corporate green technology innovation, and corporate green technology innovation enhances corporate green sustainability and improves corporate ESG performance. (3) The results of the heterogeneity test confirm that the effects of digital inclusive finance and corporate green technology innovation on corporate ESG performance have industry heterogeneity and pollution degree heterogeneity. In terms of industry heterogeneity, the effect of digital inclusive finance on the ESG performance of manufacturing corporates is more obvious, while the effect of corporate green technology innovation on the ESG performance of water, environment, and public service corporates is more obvious. In terms of pollution degree heterogeneity, the positive effect of digital inclusive finance and corporate green technology innovation on ESG performance of heavily polluting corporates is more obvious because of the greater demand effect of financing to support green technology innovation to promote green output. (4) In conducting robustness tests, it can be found that digital inclusive finance has a marginal decreasing effect on corporate ESG performance, while corporate green technology innovation has a marginal increasing effect on corporate ESG performance.

Policy recommendations

Based on the research results, this paper puts forward the following policy recommendations.

First, continue to promote the reform of traditional financial models and improve the financial service system. Taking China as an example, China's digital inclusive finance is in a rapid development stage, and there are still imperfections in the institutional mechanism of digital inclusive finance in the development process, such as imperfect credit system for small and micro corporates, opaque credit process, and stability of operating system. Therefore, it is necessary for financial regulators in each country to continue to deepen the reform of traditional financial institutions and promote the digitalization of traditional financial institutions on the one hand; on the other hand, they need to consider the development characteristics of digital inclusive finance to formulate targeted regulatory programs. On the other hand, it is necessary to consider the development characteristics of digital inclusive finance to formulate targeted regulatory programs.

Second, releasing the development dividend of digital inclusive finance and promoting corporates' green technology innovation. Enterprises should pay attention to the R&D and production of green innovation technologies. Focus on the green innovation R&D projects of corporates and guide the investment and financing services of digital inclusive finance to align with the green innovation R&D of corporates. Create a digital credit platform for corporates and promote the certification of online green innovation projects. Online financial institutions can obtain information about corporates through real-time information sharing, timely assess the green development capability of corporates, narrow the information asymmetry between corporates and financial institutions, and help corporates realize green transformation.

Third, the digital inclusive finance platform is guided to form ESG scores with corporates linked to ESG investment and financing, and corporates integrate green technology innovation into ESG performance assessment. On the one hand, the ESG performance score of corporates can serve as an important indicator to help financial institutions obtain information on corporate development and attract investment attention. Therefore, linking corporate ESG performance scores with corporate investment and financing capabilities will force companies to better fulfill their information disclosure responsibilities and help them achieve green development. On the other hand, we encourage corporates to continuously implement the concept of sustainable green development and make corporate green technology innovation as one of the indicators to measure the fulfillment of environmental responsibility in corporate ESG performance. Through green technology innovation, corporates can meet the needs of consumers and society for a better environment. Reflecting on the ESG performance of corporates, the improvement of corporates' own innovation ability can increase the corporate value; promote the corporate's environmental performance, social performance, and internal performance; and help corporates achieve high-quality development through green innovation.

Author contribution Wenqi Li analyzed and explained the intrinsic relationship between digital inclusive finance, corporate green technology innovation, and corporate ESG performance and was the main contributor to writing the manuscript. Wenbin Pang conducted the testing and collected data for the empirical part of the paper. All authors read and approved the final manuscript.

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Data availability Due to the data in the article, the authors need to do additional research for another article; participants of this study do not agree for their data to be shared publicly, so supporting data is not available. If readers have data needs, please contact the co-authors of this article: Pang Wenbin (e-mail: pangwenbin0805@163.com).

Declarations

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