

Lin, Boqiang; Xu, Chongchong

Article

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Digital inclusive finance and corporate environmental performance: Insights from Chinese micro, small- and medium-sized manufacturing enterprises

Boqiang Lin^{*}, Chongchong Xu

School of Management, China Institute for Studies in Energy Policy, Xiamen University, Fujian, 361005, PR China

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ABSTRACT

Extensive research has discussed digital inclusive finance's (DIF) rapid growth in financial services and its vital economic role; however, limited research addresses its potential to mitigate micro, small- and medium-sized enterprise (MSME) financing constraints and generate environmental benefits. This study empirically investigates the effects of DIF on Chinese MSMEs' environmental performance using a substantial manufacturer sample. The findings indicate that DIF significantly reduces the wastewater discharge intensity of MSMEs. Furthermore, DIF has a more pronounced environmental effect on non-state-owned firms, SMEs, firms in areas with more significant emission reduction pressure, and those in the eastern region. Further mechanism analysis reveals that DIF can ease the financing constraints of MSMEs. Moreover, strengthening terminal treatment, optimizing the energy consumption structure, and increasing investment in research and development are significant pathways through which DIF affects corporate environmental performance. Finally, this study proposes some policy implications to promote the green transformation of MSMEs.

1. Introduction

During this global economic sustainability recovery period, China must accelerate greening and decarbonizing its economic and social systems to achieve high-quality economic development (Razzaq & Yang, 2023). As the foundation of the modern Chinese economy, micro, small- and medium-sized enterprises (MSMEs) are vital pillars supporting the resilience of the Chinese economy and employment while simultaneously assuming a critical mission of promoting green and low-carbon transformation (Meng et al., 2018). By 2021, the number of Chinese MSMEs will reach 48 million businesses, accounting for 99.8% of all corporate entities and generating 79.4% of total employment within the enterprise sector.¹ Therefore, the issue of MSMEs' pollution and carbon emissions cannot be underestimated. In 2010, 53% of China's total carbon dioxide emissions came from MSMEs, while from the value chain perspective, the proportion was as high as 65% (Meng et al., 2018). Thus, improving the environmental performance of MSMEs at the micro level is critical for China's transition to green and low carbon.

Efficient and convenient financial support services facilitate the

smooth implementation of MSMEs' green transformations. Emission reduction is financially demanding for enterprises (Xu & Kim, 2022; Zhu & Xu, 2022). Lack of adequate financial support has emerged as a significant deterrent, compelling enterprises to abstain from environmental investments (Dang et al., 2022; Khanday et al., 2023); however, due to the severe information asymmetry between financial resource providers and MSMEs, the latter face higher transaction costs in financing, causing a more severe financing constraint predicament (Chong et al., 2013). China's conventional financial sector also suffers from a pronounced structural imbalance between financing patterns and financial supply, intensifying MSMEs' funding challenges. Assessment data from the World Bank in 2018 estimates that the potential financing demand for China's MSMEs is around 4.4 trillion US dollars (USD); however, the potential financing gap is as high as 1.9 trillion USD, with a shortfall ratio of 43.18%. Therefore, the Chinese economy urgently requires MSMEs to infuse innovative vigor and sustainable momentum. Precision financial support measures must be implemented to alleviate the challenges of MSMEs' difficulties and the high cost of financing, which are pressing and critical issues.

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^{*} Corresponding author.

E-mail addresses: bqlin@xmu.edu.cn, bqlin2004@vip.sina.com (B. Lin), ccxu_ep@163.com (C. Xu).

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With the rapid advancement of cutting-edge information and communication technologies, conventional financial services have become intricately intertwined with digital innovations, leading to the emergence of DIF. The convenience, high information-sharing, and low operational cost attributes of DIF effectively compensate for the inadequacies of conventional financial services and reduce the barriers for MSMEs to obtain financial resources (Ozili, 2018; Sharma & Changkati, 2022). On the one hand, DIF can dismantle the information barriers entrenched in conventional finance. Integrating personal, corporate, and industry data to establish credit evaluation systems can efficiently solve the information asymmetry issue, thus exploring the long-tail market of financial services (Ozili, 2018). On the other hand, DIF can surmount the temporal and spatial constraints inherent in traditional finance (Geng & He, 2021). Transitioning digital technologies to traditional financial formats can effectively accelerate the interactive flow of information, enhancing the search and matching efficiency of financial resource supply and demand parties (Z. Li et al., 2023), effectively catering to the “small quantity” and “frequent urgency” funding needs of MSMEs. Theoretically, the emergence of DIF can alleviate the financing constraints of MSMEs and is expected to dredge the financing channels for MSMEs. Against the backdrop of green and low-carbon transformation, can digital technology-driven financial innovation alleviate the financing constraints faced by MSMEs and thereby generate environmental dividends? Clarifying this question is essential for developing precise, differentiated, and efficient policy solutions to leverage DIF toward promoting green economic development.

From the policy practice perspective, no robust and reliable policy solution currently exists for overcoming the financing constraints and barriers MSMEs face in transitioning to green and low-carbon operations. On the one hand, the support MSMEs receive from green financing instruments is severely inadequate. Although green finance instruments, such as green loans and green bonds, are thriving in China (Han & Liu, 2023), most of these tools are linked to carbon emissions data, and funds flow mainly to large enterprises in industries such as energy, manufacturing, and transportation for energy efficiency improvements. MSMEs looking to undergo green transformation face difficulties in obtaining green financing support; however, the potential effects of the burgeoning DIF tools in alleviating financing difficulties for MSMEs and whether they could empower the green and low-carbon transition of MSMEs remain uncertain. The environmental and ecological effects of DIF have been preliminarily discussed in the literature, but no consensus has been reached. Cao et al. (2021) conducted a study using data at the provincial level in China. They found that DIF enhances the pure technical efficiency of energy-environmental performance rather than scale efficiency, with green technological innovation as a critical influencing mechanism. Hao et al. (2023) obtained similar evidence from prefecture-level city data. Conversely, Huang et al. (2022) identified a non-linear, U-shaped relationship between DIF and energy-environmental performance. DIF may trigger consumer expansion and green innovation effects, with the former potentially harming energy-environmental performance, while the latter enhances it. The extant research regarding the impact of DIF on regional pollution emissions is inconclusive, necessitating micro-level investigations to assess DIF's influence on tangible emission mitigation entities directly.

DIF is currently the most mainstream financial tool for alleviating financing constraints in MSMEs. Scientifically and accurately assessing whether DIF can generate environmental benefits is essential for developing practical and reliable policies for the integrated development of DIF and green finance. Current research on the environmental performance impacts of DIF on MSMEs from a micro perspective remains limited, focusing mainly on groups of listed companies regarding the influence of DIF on corporate environmental, social, and governance (ESG) performance (Mu et al., 2023; Ren et al., 2023). Research on listed firm samples faces the risk of selection bias; thus, related findings may not apply to MSME groups, which hinders understanding of the environmental performance impacts of DIF on MSMEs. Therefore, this study

focuses on MSMEs, a vital microlevel emission reduction entity, examining how DIF influences corporate pollution emission decisions from a financing constraint lens. We selected a sample of MSME manufacturers from the National Tax Survey Database (NTSD) and matched it with the city-level Peking University Digital Financial Inclusion Index of China (PKU-DFIIC),² ultimately obtaining a unique dataset. Based on this database, we investigate the impact and potential mechanisms of DIF on MSMEs' environmental performance.

This study contributes to the existing literature in three aspects. First, we focus on MSMEs, a pivotal focus of inclusive finance initiatives in China, providing new micro-level evidence to clarify the environmental impact of DIF. This study narrows its sample scope to MSMEs, enhancing the precision and reliability of assessing the environmental benefits of DIF. Notably, prior research has explored the effects of DIF on green innovation and ESG performance within listed companies (Xin Li et al., 2022; Mu et al., 2023; Ren et al., 2023); however, these studies are based on samples of publicly listed enterprises and inherently suffer from sample selection bias issues, rendering their findings potentially ineffective in guiding the green transformation of MSMEs. Consequently, this study expands the research scope to include MSMEs, facilitating the provision of novel insights to guide the high-quality development and green transformation of MSMEs.

Second, this study explores the influence channels through which DIF affects the environmental performance of MSMEs. From the perspective of alleviating financing constraints, this paper reveals the underlying mechanisms of DIF affecting corporate environmental performance from three aspects: strengthening terminal treatment, optimizing energy consumption structure, and increasing research and development (R&D) investment, providing new implications for guiding and promoting pollution reduction among MSMEs. This study provides novel Chinese evidence to the literature on financing constraints' negative environmental externalities through meticulous mechanism analysis (Bartram et al., 2022; Xu & Kim, 2022).

Third, this paper conducts heterogeneous analysis across enterprise characteristics, such as ownership and scale, and regional dimensions, such as emission reduction pressures and geographic location, to comprehensively elucidate DIF's heterogeneous environmental effects. The findings provide tailored empirical guidance on China's digital financial policies that support a green, low-carbon economic transition.

The remaining sections are arranged as follows. Section 2 comprises a comprehensive review of the literature and describes the theoretical foundation of the research. Section 3 provides details of the methodology. Section 4 showcases and deliberates the empirical test outcomes. Finally, the research conclusions and related policy implications are presented in Section 5.

2. Literature review and theoretical analysis

2.1. Literature review

Clarifying MSMEs' financing constraints and the resulting environmental consequences is pivotal in solidifying this study's foundational logic. Scholars have extensively deliberated the origins of financing constraints for MSMEs, positing that a confluence of factors, such as information asymmetry between financial institutions and businesses (Schmidt-Mohr, 1997), elevated transaction costs (Honohan, 2004), and poor financial structural adaptability (Strahan & Weston, 1998),

² The rationale for selecting MSMEs as the research sample is as follows. The original data used for this study's digital inclusive finance index primarily comes from and targets MSMEs. DIF helps MSMEs obtain financing support more quickly and conveniently; therefore, we posit that DIF mainly affects the environmental performance of MSMEs. The classification criteria for large, medium, small, and microindustrial enterprises are from the National Bureau of Statistics, as indicated in Table A1.

collectively contribute to the financing predicaments that MSMEs encounter. MSMEs' financing constraints affect their financial viability and profoundly impact environmental sustainability. Specifically, funding limitations impede MSMEs from investing in eco-friendly technical renovations and clean production (Cai & Li, 2018), perpetuating high-pollution and high-emission operations. When MSMEs face a financing constraint, they often ignore environmental pollution control. Tian and Lin (2019) identified that moderate and significant obstacles in financing activities undermine enterprises' environmental performance through high investment costs and biased incentive measures. Dang et al. (2022) observed that enterprises unrestricted by financing constraints tend to allocate greater resources to future pollution control efforts. Xu and Kim (2022) discovered that reducing the financing constraints on enterprises can diminish harmful gas emissions within enterprises through three distinct quasi-natural experimental settings. Innovating and improving financial instruments to stimulate their effect of alleviating financing constraints on MSMEs is an important measure to promote green investment and environmental governance.

Due to the notable accessibility, interconnectedness, and systematic nature of modern information technology, the development of DIF possesses significant advantages in alleviating the challenges of "difficulty in financing" and "high financing costs" facing MSMEs (C. Li et al., 2023; Lu et al., 2022). Agarwal and Hauswald (2010) proposed that online lending in the Internet finance environment has more relaxed loan approval than traditional financing, which helps reduce financing thresholds for MSMEs. Hau et al. (2017) examined the loans provided by Ant Financial Services Group to micro and small merchants. They found that the credit risk control model implemented through big data, artificial intelligence, and other technologies can help MSMEs remove financing dilemmas while managing risks. Lu et al. (2022) believed that DIF and local small- and medium-sized banks demonstrate substitution effects in alleviating financing constraints for MSMEs. Based on the fundamental consensus that DIF can alleviate financing constraints, scholars further discussed the impact of DIF on enterprises from multiple perspectives. For example, Chen and Zhang (2021) proposed that DIF can promote manufacturing serviceization by enhancing innovation intensity and elevating digitization. Tang et al. (2022) used data from Chinese A-share listed companies from 2011 to 2018, determining that DIF could enhance the value of emerging strategic enterprises through three channels: supplementary funding, risk reduction, and innovation promotion. Finally, Xiong et al. (2023) tested the innovation incentive effect of DIF, while L. Jin, Dai, et al. (2023) suggested that DIF can effectively mitigate resource misallocation among firms, thereby contributing to the enhancement of total factor productivity.

Furthermore, numerous studies found that DIF can optimize the allocation of financial resources between sectors, compensate for the shortcomings of traditional finance (C. Li et al., 2023; Lu et al., 2022), and generate ecological benefits. At the macro level, the widespread integration of DIF within the socioeconomic framework has engendered extensive discourse regarding its environmental impacts (Cao et al., 2021; Hao et al., 2023; Huang et al., 2022). Sun et al. (2023) empirically assessed the impact of DIF on energy-based carbon intensity. They found that a 1% increase in DIF would reduce carbon intensity by approximately 0.092%, with technical innovation and energy structure mediating. Furthermore, Shen et al. (2023) used 2011–2018 Chinese provincial panel data and discovered that DIF improves sustainable total-factor eco-efficiency by expanding green credit scale and elevating green and digital technology innovation levels. G. Li, Wu, et al. (2023) suggested that DIF can effectively alleviate the mismatch between the supply and demand of financial resources, thereby exerting a substantial impetus on the transition toward low-carbon energy. Using China's urban-level data from 2008 to 2019, Razzaq and Yang (2023) discovered that DIF significantly promotes green economic growth by facilitating the digital transformation of enterprises and alleviating energy poverty. These macroscopic studies provide insights into comprehending the ecological and environmental benefits of DIF; however, we must

acknowledge the necessity of a more detailed micro-level analysis to comprehensively unveil the mechanisms and ramifications of DIF in enhancing ecological benefits. Such an approach can provide tailored recommendations for precision-driven policy formulation and implementation.

Some studies have examined the impact of DIF on firms' sustainable performance from a micro-level perspective. Based on data from heavily polluting Chinese enterprises between 2011 and 2020, Ding et al. (2023) discovered that DIF could significantly promote corporate green investment; this effect was primarily achieved by stimulating internal capital flows and intensifying market competition. Additional literature examined the impact of DIF on corporate green transformation from an innovation perspective. For example, Kong et al. (2022) proposed that DIF can promote green technology innovation in enterprises. Digital financial institutions can alleviate information asymmetry in green innovation markets through digital technologies like big data analysis and directly promote enterprise innovation behavior. DIF can improve the quality of enterprise environmental information disclosure and reduce financing constraints, indirectly enabling green innovation activities. Xin Li et al. (2022) arrived at similar conclusions, finding that for every 1% increase in DIF, green innovation increased by 0.82%. Mu et al. (2023) and Ren et al. (2023) also empirically investigated the effectiveness of DIF in promoting corporate sustainability from an ESG perspective.

Nevertheless, some limitations remain in discussing how DIF affects corporate green transformation. First, most studies focused on listed companies and not the actual focus of DIF services: MSMEs. Second, due to data limitations, existing research has only considered indirect indicators of enterprise environmental performance, such as green investment, green innovation, and ESG performance. This approach has been unable to accurately assess the impact of DIF on enterprises' real pollutant emissions information. This study addresses these gaps, using a dataset of manufacturing MSMEs that includes financial and operational information, energy use, and pollutant emissions information. This approach allows us to theoretically and empirically analyze the environmental benefits and action mechanisms of DIF.

2.2. Theoretical analysis

Traditional finance cannot facilitate adequate access to banking credit services for MSMEs. This shortcoming can be attributed to the mismatch of financial resources caused by scale discrimination, ownership discrimination (Chong et al., 2013), and geographical limitations in the provision of financial services (Lu et al., 2022). According to Collard et al. (2001), the financial market possesses exclusions of opportunity, condition, price, market, and self, and disadvantaged groups represented by small and microenterprises are often the victims of the "Pareto principle" in financial activities. DIF, as an innovative form of finance empowered by internet technology, can effectively address the issue of inadequate funding for MSMEs through three key aspects. First, DIF facilitates the alleviation of information asymmetry among financial institutions and enterprises. According to information economics theory, the borrower possesses more information regarding their credit and risk than the lender in corporate financing; the borrower and lender are in a typical state of information asymmetry. Financial institutions can leverage digital financial technology to stay informed about the operational dynamics of MSMEs and obtain relevant credit information for risk management (Kong et al., 2022). Simultaneously, MSMEs and potential fund providers can access abundant lending information and engage in mutual matching, enhancing transaction probability (Ozili, 2018). Second, DIF can alleviate the high financing costs of underestimating corporate creditworthiness (C. Li et al., 2023). DIF enables more precise credit risk assessments of MSMEs through advanced analytics, allowing creditworthy businesses to obtain financing at lower interest rates and reduce the cost of capital (Tang et al., 2022). Additionally, DIF can streamline intricate loan procedures,

thus reducing transaction costs arising from protracted lending processes. Third, DIF enables novel communication and interaction between lenders and borrowers by providing innovative financial products and services through digital channels such as the internet, personal computers, mobile devices, and contactless cards linked to digital payment systems (Ozili, 2018). By conducting lending operations online, digital financial institutions can transcend geographical constraints and impose more lenient collateral requirements on borrowing enterprises, thereby facilitating the diversification of financing channels for MSMEs (Al-Smadi, 2023). Hence, this study posits that DIF can alleviate the financing constraints of MSMEs.

In corporate production and business practices, environmental investments, such as green technology R&D innovation, production process upgrades, and pollutant treatment equipment installation, generally have long cycles, low returns, and high risks (Shi et al., 2008). Particularly for MSMEs facing tighter financing constraints, the lack of funding forces them to reduce investment in non-revenue-generating environmental projects (Tian & Lin, 2019; Zhang & Zheng, 2019). Fan et al. (2021) discovered that under strict green loan regulations, large enterprises could upgrade emission technologies responsively due to sufficient funding, whereas small enterprises lacking adequate green investment finances could only reduce emissions by cutting production. Thus, addressing the financing difficulties and high capital costs faced by MSMEs is a critical foundation for facilitating their transition toward green and sustainable operations. The financing constraint relief from DIF reduces the cash flow pressures MSMEs face and somewhat mitigates environmental investment risks. Alleviating financing constraints is widely seen as beneficial in promoting corporate investments in environmental governance (Dang et al., 2022; Xu & Kim, 2022; Yu et al., 2022). Therefore, we believe that DIF can help MSMEs reduce pollution emissions by easing their financing constraints. Fig. 1 posits that DIF may enhance corporate environmental performance through three channels: strengthening terminal treatment, optimizing energy structure, and increasing R&D investment.

First, the alleviation effect of DIF on financing constraints can enable MSMEs to acquire additional funding for pollution control, thus enhancing their capacity for terminal treatment and regulation of pollution. The end treatment of pollution usually refers to removing pollutants generated in the production process by installing pollution control equipment to reduce the concentration of pollutant emissions (Du et al., 2022). When engaging in terminal pollution control, enterprises require substantial capital investment in environmental restoration, emission reduction, and pollutant management (Yu et al., 2022). By mitigating financing constraints, enterprises can better strategize and implement environmental governance measures (Zhou et al., 2023; Zhu

et al., 2022), foster sustainable development, and establish a long-term operational mindset, strengthening pollution governance at the end stage. Zhang et al. (2019) demonstrated that enterprises subject to financial constraints exhibit more prudent investment behaviors regarding industrial equipment to mitigate waste gas emissions; however, with access to effective financing channels, these enterprises may opt to boost investments in waste gas treatment solutions to curb emissions. Based on the exogenous shock of *anti-recharacterization* laws enacted in several states in the US, Attig (2023) discovered that relaxing financing constraints enables firms to undertake more social responsibility and facilitates transitions toward ethical corporate behavior. Furthermore, Ding et al. (2023) suggested that the relaxation of financing constraints enabled by digital finance can substantially promote green investments among heavily polluting firms.

Second, the alleviation effect of DIF on financing constraints can reduce MSMEs' reliance on conventional energy consumption methods and promote their transition toward cleaner and renewable energy use. For a long time, China's energy resource endowment characterized by "rich coal, lack of oil and gas" has led to coal being the primary energy source for Chinese enterprises' energy consumption (J. Li & B. Lin, 2016). Promoting a clean transformation of the energy consumption structure is a critical way to reduce pollution for enterprises (Du et al., 2022). In recent years, the Chinese government has implemented environmental regulations and energy consumption constraint policies to encourage enterprises to adopt clean production methods and optimize energy consumption upgrading (Lin & Li, 2021; Zhu & Xu, 2022); however, in practical production, transforming the energy consumption structure to clean energy is not easy. Due to the substantial financial investment required for the research and application of clean energy technologies, MSMEs usually struggle to bear these costs when facing financing constraints (Dang et al., 2022). After easing financing constraints through DIF channels, MSMEs can more easily acquire funding for the development and adoption of clean energy technologies, thereby optimizing the structure of energy consumption (Yang et al., 2018), reducing dependence on traditional high-carbon energy sources (Song et al., 2022), and improving their environmental performance. Lu et al. (2023) discovered that under the stimulus of DIF, firms reduced fossil fuel consumption and increased the share of renewable energy in energy consumption. A cleaner energy consumption mix can facilitate notable improvements in firms' environmental performance (Du et al., 2022; Lin & Li, 2022).

Third, the alleviation effect of DIF on financing constraints can incentivize MSMEs to augment their R&D expenditures (Xin Li et al., 2022), thereby propelling the application of environmentally friendly technologies and processes (Han & Liu, 2023). Antweiler et al. (2001)

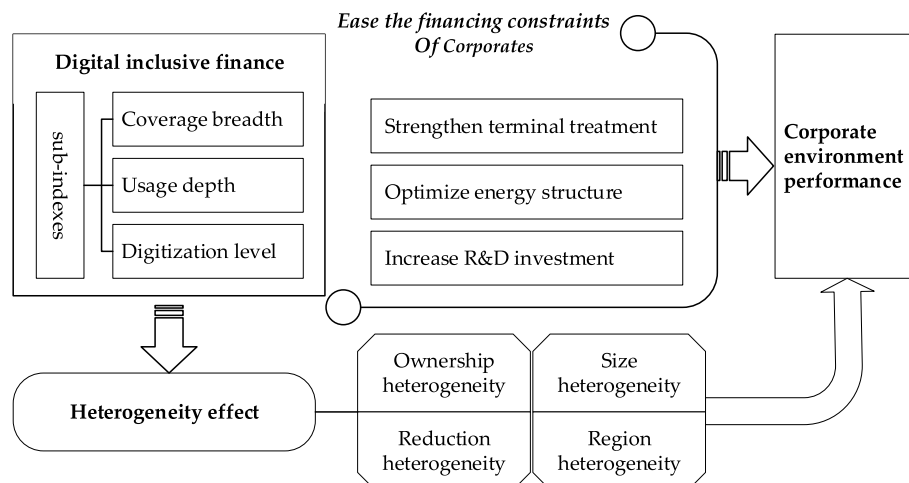


Fig. 1. Research framework.

proposed that technological progress can transform traditional technologies into cleaner ones, thereby reducing the polluting by-products generated during production. Rubashkina et al. (2015) argued that the optimal choice for enterprises under environmental regulation is to improve energy use and reduce pollution emissions through technological progress, emphasizing that technological innovation is the key to achieving a win–win situation for both the economy and the environment. Therefore, increasing R&D investment to enhance technological innovation strength is the key for enterprises to obtain green competitiveness (Lee & Min, 2015). DIF makes it easier for MSMEs to obtain credit, broadens their funding sources, and increases financing, thereby helping to promote their investment in R&D. Tang et al. (2022) argued that digital finance could help provide firms with adequate funding for R&D activities, thereby enabling technological breakthroughs. Xin Li et al. (2022) and Xiong et al. (2023) also found that by alleviating financing constraints on firms, digital finance can promote corporate R&D investments and generate remarkable innovation effects. Heightened investment in R&D helps stimulate corporate exploration and the adoption of novel clean technologies, energy-efficient techniques (K. Li & B. Lin, 2016), and pollution control methods, thereby reducing energy consumption, waste emissions, and environmental pollution during the production process (Alam et al., 2019). Chen et al. (2023) examined the impact of bank deregulation on corporate environmental performance. They discovered that improved corporate credit conditions facilitated substantial technology upgrades for firms, decreasing pollution emission intensity.

3. Methodology

3.1. Econometric model

This study constructs the following benchmark econometric model to examine the effects of DIF on the environmental performance of MSMEs.

$$\ln Cep_{it} = \alpha + \beta_1 Dif_{it} + \gamma X_{it} + \varphi_i + \eta_t + \lambda_{jt} + \varepsilon_{it} \quad (1)$$

where i , j , and t represent firm, industry, and year, respectively. $\ln Cep_{it}$ denotes the environmental performance of firm i in year t . Dif_{it} represents the development level of DIF in the city where firm i is located in year t . X_{it} denotes the set of control variables encompassing both firm-level and city-level factors. φ_i , η_t and λ_{jt} represent firm fixed effect, year fixed effect, and industry-year fixed effect, respectively. ε_{it} denotes the random perturbation term. Standard errors are clustered at the firm level to address potential autocorrelation and heteroscedasticity concerns.

3.2. Variables

3.2.1. Explained variable

Corporate environmental performance ($\ln Cep$) is this paper's explained variable. Existing studies have not reached a consensus on assessing corporate environmental performance. Typically employed indicators for measuring environmental performance include carbon emission intensity (Ren et al., 2022; Zhu et al., 2022), environmental rating (Escrig-Olmedo et al., 2017), environmental information disclosure (Meng & Zhang, 2022), environmental punishment (Wang et al., 2018), and frequency of environmental-related vocabulary (X. Jin et al., 2023); however, these indicators fail to effectively depict a firm's overall environmental quality (Zhou et al., 2023). It is more comprehensive and rational to assess corporate environmental performance by employing actual data on pollutant emissions (Chen et al., 2023). Given data availability, this study employs the logarithm of sewage discharge intensity (total sewage discharge/total industrial output) to assess corporate environmental performance. Furthermore, this study employs the logarithm of industrial exhaust emission intensity in robustness tests to assess corporate environmental performance.

3.2.2. Explanatory variable

The development level of DIF in the prefecture-level city where the firm is located is the core explanatory variable measured by the PKU-DFIIC (Guo et al., 2020). Based on the characteristics of DIF services and data accessibility, the indicator system for DIF is structured around coverage breadth, usage depth, and digitization level (see Table A2). The coverage breadth subdimension mainly includes the account coverage index, which reflects the coverage of DIF services. The usage depth subdimension comprehensively measures the use of DIF from various businesses, such as payment, credit, insurance, monetary funds, and investment, reflecting the deepening degree of DIF. The digitization level subdimension reflects the convenience of DIF from the perspectives of mobility, affordability, and credit. To enhance the study's comprehensiveness, we also investigate the effects of subdimensions, such as coverage breadth, use depth, and digitization level, on the environmental performance of MSMEs. Furthermore, we conduct robustness tests by employing provincial-level and county-level PKU-DFIIC to gauge the development level of DIF in the region where the firm is located.

3.2.3. Control variables

This study's econometric model incorporated firm and city-level control variables. Firm-level controls include (1) corporate age, as the age of a firm is an important factor affecting its environmental performance due to technological obsolescence, change resistance, institutional inertia, and unwillingness to invest in sustainable practices (Amahalu, 2019). We also include (2) corporate ownership because the ownership structure and owners' values, priorities, and incentives can shape a firm's environmental agenda and actions. Generally, state-owned and non-state-owned firms adopt distinct environmental governance strategies, resulting in varying environmental performance (Wang et al., 2022). (3) Corporate scale is included because larger corporations often possess more resources and capabilities to invest in environmentally friendly technologies. They also implement sustainable practices and achieve operational efficiencies compared to smaller enterprises with limited scale advantages, leading to better environmental performance (Amahalu, 2019). (4) Export situation is included as export-oriented firms may encounter stricter scrutiny and pressure to comply with the environmental regulations and sustainability standards imposed by importing countries. This situation links a firm's environmental strategy to export activities (Martín-Tapia et al., 2010). Finally, we include (5) labor productivity since higher labor productivity can indicate the ability to produce more output with the same or fewer inputs, leading to increased efficiency in resource utilization, reduced waste generation, and improved environmental performance by minimizing environmental impacts (Cui et al., 2016).

City-level controls include (1) Economic development: Regional economic growth may exacerbate environmental burdens because increased industrial activities and consumption levels can result in excessive resource exploitation, energy consumption, and environmental pollution. Conversely, with the rise in social awareness and the impetus of technological innovation, higher levels of economic development are often associated with improved infrastructure, advanced technologies, and stricter environmental regulations. These factors foster an environment conducive to sustainable practices, resource efficiency, and pollution reduction (X. Ouyang, Liao, et al., 2023; Shao et al., 2016), potentially positively impacting a firm's environmental performance. (2) Industrial structure: The urban industrial structure significantly influences the types and scale of an enterprise's economic activities. Enterprises will likely face formidable environmental challenges and exhibit lower environmental performance if the urban industrial structure leans toward industries with high pollution and energy consumption. Conversely, if the urban industrial structure tends toward clean energy, environmental technologies, and green industries, local enterprises are more likely to adopt sustainable business strategies, enhancing their environmental performance (Su & Fan, 2022). (3) Fiscal

expenditure: Existing research indicates a complex relationship between fiscal expenditure and environmental pollution (Elheddad et al., 2020). For example, Lin and Zhou (2021) found that Chinese-style fiscal decentralization and vertical fiscal imbalance may give rise to substantial incentive distortions that are harmful to the governance of the public environment. (4) Population density: Higher population density often correlates with increased economic activity and industrialization, resulting in more pronounced resource and environmental pressures (Frank & Engelke, 2005). Enterprises should emphasize environmental management and emission reduction measures when conducting production and operations in densely populated areas. This approach can address the environmental challenges associated with population density and meet governmental and public expectations for environmental conservation (Chen et al., 2020). Table 1 reports a description of the primary variables in the research.

3.3. Data sources and descriptive statistics

The research data covers 2013–2016 and is sourced as follows. (1) PKU-DFIIC depicts the development level of DIF in the respective regions where the firms are situated. (2) NTSD, which provides the necessary information regarding the production, operation, finance, and pollution emissions of MSMEs required for this study. (3) The China City Statistical Yearbook is the source of city-level control variables. Table 2 reports the descriptive statistics of the primary variables.

4. Empirical results

4.1. Baseline results

Based on the Hausman test results, this study uses a panel fixed-effects model to empirically investigate the impact of DIF on the environmental performance of MSMEs. Table 3 presents the results of Model (1), indicating that the estimated coefficients of DIF are significantly negative at the 1% level. This result suggests that DIF contributes to reducing sewage discharge intensity by MSMEs, thus yielding environmental benefits. From the economic implications of the results in Column (4), a 1 unit increase in the level of DIF in an enterprise's region leads to a 1.4% average decrease in the enterprise's sewage discharge intensity. Empirical evidence points to DIF as an impactful policy tool for unlocking pollution abatement potential in the MSME sector. These

Table 1
Variable description.

Variable	Definition	Measurement
<i>lnCep</i>	Corporate environmental performance	Total sewage discharge/total output value, logarithm
<i>Dif</i>	Digital inclusive finance	PKU-DFIIC (Prefecture-level city index)
<i>Dif_coverage</i>	Coverage breadth	PKU-DFIIC (Sub-dimension index)
<i>Dif_depth</i>	Usage depth	PKU-DFIIC (Sub-dimension index)
<i>Dif_digitization</i>	Digitization level	PKU-DFIIC (Sub-dimension index)
<i>Age</i>	Corporate age	Year - opening year + 1
<i>Soe</i>	Corporate ownership	1 for state-owned firms and 0 otherwise
<i>lnScale</i>	Corporate scale	Total assets at year-end, logarithm
<i>Exp</i>	Export	1 for export firms and 0 otherwise
<i>Lp</i>	Labor productivity	Business revenue/number of employees
<i>lnPergdp</i>	Economic development	Real GDP/total population, logarithm
<i>Is</i>	Industrial structure	Secondary industry output/tertiary industry output
<i>lnFe</i>	Fiscal expenditure	Fiscal expenditure/GDP, logarithm
<i>lnPop</i>	Population density	Total population/administrative area, logarithm

Notes: PKU-DFIIC represents the Peking University Digital Financial Inclusion Index of China.

Table 2
Descriptive statistics.

Variable	Obs	Mean	Median	S.D.	Min	Max
<i>lnCep</i>	46486	−9.480	−9.770	2	−14	6.790
<i>Dif</i>	46486	176	173	30.600	73.300	247
<i>Dif_coverage</i>	46486	176	178	36.200	25.500	254
<i>Dif_depth</i>	46486	166	167	32.800	54	251
<i>Dif_digitization</i>	46486	193	174	39.800	95.500	500
<i>Age</i>	46486	13.100	12	5.750	3	39
<i>Soe</i>	46486	0.015	0	0.121	0	1
<i>lnScale</i>	46486	11.500	11.500	1.350	6.110	14.600
<i>Exp</i>	46486	0.437	0	0.496	0	1
<i>Lp</i>	46416	0.076	0.044	0.128	5.37e-05	6.320
<i>lnPergdp</i>	46186	2.060	2.080	0.825	−0.409	3.770
<i>Is</i>	46446	1.090	1.070	0.377	0.210	6.770
<i>lnFe</i>	46446	7.190	7.120	0.374	6.330	9.280
<i>lnPop</i>	45584	6.350	6.460	0.677	1.660	7.880

Table 3
Baseline results.

Variable	<i>lnCep</i>			
	(1)	(2)	(3)	(4)
<i>Dif</i>	−0.016*** (−5.629)	−0.013*** (−4.281)	−0.013*** (−4.610)	−0.014*** (−4.615)
<i>Age</i>			0.182* (1.857)	0.156 (1.548)
<i>Soe</i>			0.190 (1.070)	0.190 (1.036)
<i>lnScale</i>			−0.317*** (−8.071)	−0.320*** (−8.076)
<i>Exp</i>			0.031 (0.592)	0.034 (0.624)
<i>Lp</i>			−1.492*** (−7.029)	−1.483*** (−6.944)
<i>lnPergdp</i>				0.085 (0.702)
<i>Is</i>				−0.066 (−0.478)
<i>lnFe</i>				0.421** (2.510)
<i>lnPop</i>				−0.941*** (−3.308)
<i>Constant</i>	−6.725*** (−13.730)	−7.280*** (−14.144)	−5.793*** (−3.928)	−2.422 (−0.933)
<i>Firm FE</i>	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y
<i>Industry-Year FE</i>	N	Y	Y	Y
<i>Obs</i>	46486	46210	46115	45142
<i>adj. R²</i>	0.377	0.407	0.409	0.409

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. The t statistics are indicated in parentheses. Column (1) controls firm and year fixed effects, while Column (2) controls for industry-time fixed effects. Column (3) incorporates firm-level control variables based on Column (2), and Column (4) further includes city-level control variables.

findings are consistent with Mu et al. (2023) and Ren et al. (2023), who found that DIF can alleviate corporate financial constraints and improve ESG performance. Furthermore, Ding et al. (2023) proposed that DIF is an essential engine driving green investment in enterprises. Kong et al. (2022) corroborated the ecological benefits of DIF from the perspective of facilitating green technology innovation. Moreover, our findings support macro-level studies on the environmental benefits of DIF (Cao et al., 2021; Hao et al., 2023; Huang et al., 2022; Sun et al., 2023). Based on transaction cost economics (Williamson, 1981) and elaborated by Lu et al. (2022), DIF can effectively alleviate the financing constraints faced by MSMEs through streamlined transaction mechanisms and robust digital authentication methods. This situation increases lending to MSMEs, enabling investment in cleaner production processes according to the environmental Kuznets curve hypothesis (Grossman & Krueger, 1991). Therefore, DIF provides the necessary financial support for

MSMEs, helping them maximize their potential for green transformation and catalyzing emission-mitigation efforts across the MSME sector. This situation expedites China's transition to a sustainable low-carbon economy consistent with its long-term decarbonization roadmap.

Based on the estimated coefficients of firm-level control variables, corporate scale, and labor productivity positively improve the environmental performance of MSMEs. This finding is consistent with the expectation that the scale economy effect caused by corporate scale and the resource-saving effect caused by increased labor productivity is conducive to reducing the pollution emission intensity of MSMEs (Yu et al., 2022). Increased urban fiscal expenditure exacerbates the intensity of pollution emissions from MSMEs. This phenomenon may be attributed to insufficient guidance and oversight of regional fiscal expenditure within the framework of Chinese-style fiscal decentralization, leading to excessive investment by firms in high-pollution projects (Lin & Zhou, 2021). The *lnPop* coefficient is significantly negative, denoting that the higher the population density, the better the corporate environmental performance. This result could be attributed to firms' heightened regulatory and social pressures in densely populated areas, prompting them to implement more stringent environmental protection measures to mitigate their negative environmental impact (Chen et al., 2020).

To precisely examine which subdimensions of DIF contribute to enhancing environmental performance in MSMEs, this paper sequentially incorporates the coverage breadth index, usage depth index, and digitization level index as core explanatory variables into the baseline Model (1). Columns (1)–(2) of Table 4 indicate that the coverage breadth of DIF significantly negatively impacts the sewage discharge intensity of MSMEs. The expansion of coverage is manifested in the increase in Internet payment accounts and associated bank accounts, which can help MSMEs transcend traditional financial constraints and geographical restrictions to enjoy a higher quality and more favorable financing environment (Z. Li et al., 2023). The results in Columns (3)–(4) of Table 4 indicate that the usage depth of DIF also significantly reduces the sewage discharge intensity of MSMEs. The usage depth index is measured through the actual use of Internet financial services, reflecting the capacity of DIF to serve MSMEs. The increase in the usage depth index signifies that DIF can offer more comprehensive financial services, including credit, insurance, money funds, credit scoring, and more, thus easing the mismatch between financial supply and demand (Xiong et al., 2023). These services, in turn, help reduce financing costs for MSMEs; however, Columns (5)–(6) of Table 4 indicate that the coefficients of the digitization level index are negative but not statistically significant. The enhancement of digitization can theoretically make the payment process more efficient, the transaction chain more convenient, and the funding supply more cost-effective; however, a mere elevation in the degree of digitization cannot significantly enhance the environmental performance of MSMEs.

4.2. Treatment of endogenous issues

The baseline regression results may suffer from two endogeneity issues. First is the concern of endogeneity resulting from omitted variables. Despite controlling for firm and city-level covariates in the baseline model and firm, year, and industry-year fixed effects, it is still possible to omit certain variables that simultaneously affect DIF development and corporate environmental performance. Second, the issue of endogeneity arises due to reverse causality. MSMEs with lower pollution intensity may be more inclined toward green transformation and upgrading, driving the development of local DIF due to their financing needs. Therefore, drawing on existing research (J. Ouyang et al., 2023; Ren et al., 2023), this study employs the instrumental variable (IV) method and the difference-in-differences (DID) model to mitigate these potential endogeneity issues.

Following J. Ouyang et al. (2023), this study's IV for DIF incorporates the spherical distance between the cities where MSMEs are located and Hangzhou. Hangzhou is the birthplace of Chinese DIF, and the degree of influence of Hangzhou's DIF on nearby cities is more pronounced than on cities further away. Moreover, given the time-invariant nature of the distance variable, we estimate the IV regression outcomes by incorporating the cross-product of the distance variable and the year dummy variable. Columns (1)–(2) of Table 5 show the results of the IV estimation. Column (1) shows the first-stage result, indicating a significant negative relationship between the firm's spherical distance from Hangzhou and DIF. Column (2) represents the second-stage result, with a significantly negative estimated coefficient. This outcome implies that even after considering endogeneity issues, the role of DIF in improving the environmental performance of MSMEs remains significant.

Furthermore, referring to Liu et al. (2021), this study also employs the provincial internet penetration rate (*IV_Internet*) as an instrumental variable for DIF. The data are sourced from the China Internet Development Statistics Report. The rationale for this selection is twofold. On the one hand, the internet penetration rate signifies the degree of digital financial infrastructure development in a region, which is closely tied to the development trend of DIF. On the other hand, after controlling for variables related to corporate environmental performance, no direct causal pathway exists between the Internet penetration rate and corporate pollution emissions. The estimated results are reported in Columns (3) to (4) of Table 5. The first-stage regression results indicate that the coefficient of *IV_Internet* is significantly positive at the 1% statistical level, satisfying the relevance of the instrumental variable. The second-stage regression outcomes reveal that the coefficient of *Dif* is notably negative at the 1% statistical level, underscoring the robust conclusion that the advancement of DIF helps improve corporate environmental performance.

Referring to W. Li et al. (2022), this paper regards the “Broadband

Table 4
Impact of DIF sub-indicators on corporate environmental performance.

Variable	<i>lnCep</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Dif_coverage</i>	−0.011*** (−3.084)	−0.012*** (−3.316)				
<i>Dif_depth</i>			−0.009*** (−4.800)	−0.010*** (−4.746)		
<i>Dif_digitization</i>					−0.000 (−0.593)	−0.001 (−0.689)
<i>Controls</i>	N	Y	N	Y	N	Y
<i>Firm FE</i>	Y	Y	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y	Y	Y
<i>Industry-Year FE</i>	Y	Y	Y	Y	Y	Y
<i>Obs</i>	46210	45142	46210	45142	46210	45142
<i>adj. R²</i>	0.407	0.409	0.408	0.409	0.407	0.409

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. The t statistics are indicated in parentheses. Columns (1), (3), and (5) have not added control variables.

Table 5
Endogenous test results.

Variable	IV first stage		IV, second stage		DID estimation
	<i>Dif</i>		<i>Dif</i>		
	(1)	(2)	(3)	(4)	(5)
<i>Dif</i>		−0.117*** (−3.510)		−0.351*** (−6.061)	
<i>HZ_distance</i> * <i>D2013</i>	−0.110*** (−14.000)				
<i>HZ_distance</i> * <i>D2014</i>	−0.110*** (−13.980)				
<i>HZ_distance</i> * <i>D2015</i>	−0.109*** (−13.940)				
<i>HZ_distance</i> * <i>D2016</i>	−0.109*** (−13.890)				
<i>IV_Internet</i>			0.265*** (10.050)		
<i>Broadband China</i>					−0.199*** (−5.323)
<i>Controls</i>	Y	Y	Y	Y	Y
<i>Firm FE</i>	Y	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y	Y
<i>Industry-Year FE</i>	Y	Y	Y	Y	Y
<i>Underidentification test</i>	412.86***		103.68***		
<i>Cragg–Donald Wald F statistic</i>	63.46		100.92		
<i>Obs</i>	45142	45142	45142	45142	45142
<i>adj. R²</i>		−0.691		−0.462	0.409

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. The t statistics are indicated in parentheses. The first-stage F-statistics of the IV estimation exceed 10, thus eliminating the concern of weak instrumentation. In the DID estimation, if the city where the enterprise is located is a Broadband China Demonstration City, *Broadband China* is equal to 1; otherwise, it is equal to 0.

China Strategy” as an exogenous shock to the digital transformation of the Chinese financial system and employs the DID method to reestimate. The profound development of DIF relies heavily on the support of network infrastructure. From 2013 to 2016, 120 cities in China were selected as demonstration cities for the “Broadband China Strategy.” For the demonstration cities, the government allocated additional funds to expand the coverage of broadband networks and enhance network operation speed, generating a positive spillover effect on the development of DIF. This study treats the demonstration cities as the treatment group and the non-demonstration cities as the control group, constructing a time-varying DID model to evaluate the microenvironmental impact of the “Broadband China Strategy.” Column (5) of Table 5 shows that the coefficient of *Broadband China* is significantly negative at the 1% level, further confirming the robustness of the benchmark results.

4.3. Robustness check

4.3.1. Replacing the core variables

Given the diverse range of pollutants enterprises emit, this study substitutes the dependent variable with the logarithm of exhaust emission intensity (*ln Cep_exh*) for robustness testing. The results in Column (1) of Table 6 show that DIF significantly reduces the intensity of exhaust emissions from enterprises, confirming the fundamental conclusion that DIF contributes to enhancing corporate environmental performance.

In addition to providing indicators at the municipal level, the PKU-DFIIC furnishes information on DIF development at the provincial and county levels. Therefore, this paper sequentially employs the PKU-DFIIC indexes at the provincial and county levels to measure the development level of DIF for robustness testing in the regions where the firms are located. The results in Columns (2) and (3) of Table 6 indicate that the baseline findings remain robust even after substituting the explanatory variables.

4.3.2. Controlling for macroeconomic factors

The benchmark model incorporates city-level control variables; however, potential macroeconomic factors that could confound the

results remain. Therefore, this study further introduces province-year fixed effects in Model (1) to mitigate the interference of macroeconomic factors. The results in Column (4) of Table 6 indicate that the effect of DIF on the sewage discharge intensity of MSMEs remains significantly negative after excluding the interference of macroeconomic factors.

4.3.3. Excluding firm samples from municipalities directly under the central government

Due to the significant economic peculiarities of China’s municipalities directly under the central government, considerable disparities may exist in the development level of DIF and the regulatory intensity of the government toward MSMEs, as compared to general cities. Following Ren et al. (2023), this study excludes the sample data from Beijing, Shanghai, Tianjin, and Chongqing and conducts a new regression analysis. As shown in Column (5) of Table 6, the improvement effect of DIF on the environmental performance of MSMEs remains remarkable.

4.3.4. Eliminating interference from corporate entry or exit behavior

Some MSMEs may enter or exit during the sample period. Newly entering or exiting firms may exhibit specific characteristics and behaviors regarding environmental performance, which may introduce selection bias and sample heterogeneity that interfere with the reliability of the baseline estimation. Therefore, this study only retains firms with observations throughout 2013–2016 as the research sample for re-estimation. The results are reported in Column (6) of Table 6, showing that this study’s findings remain solid after excluding interference from corporate entry or exit behavior.

4.3.5. Tail reduction processing of the variables

We winsorized all continuous variables at the 1st and 99th percentiles to mitigate the influence of outliers on the results of this study. The results are reported in Column (7) of Table 6, showing that the estimates and significance levels of the core explanatory variables remain largely unchanged after trimming outliers, indicating that the baseline results are robust.

Table 6
Robustness test results.

Variable	$\ln Cep_{exh}$	$\ln Cep$	$\ln Cep$	$\ln Cep$	$\ln Cep$	$\ln Cep$	$\ln Cep$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Dif</i>	-0.037** (-2.156)			-0.009** (-2.230)	-0.014*** (-4.545)	-0.022*** (-3.514)	-0.018*** (-6.111)
<i>Dif_province</i>		-0.007* (-1.757)					
<i>Dif_county</i>			-0.018*** (-5.582)				
<i>Controls</i>	Y	Y	Y	Y	Y	Y	Y
<i>Firm FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Industry-Year FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Province-Year FE</i>	N	N	N	Y	N	N	N
<i>Obs</i>	4183	45142	9611	45139	42082	10132	45142
<i>adj. R²</i>	0.525	0.409	0.411	0.425	0.414	0.385	0.421

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. The t statistics are indicated in parentheses.

4.4. Heterogeneous effects

This study examines the heterogeneous effects of DIF on the environmental performance of MSMEs from four dimensions: corporate ownership, corporate scale, regional emission reduction pressure, and regional geographic location.

- (1) Corporate ownership heterogeneity: State-owned enterprises (SOEs) have long benefited from government financing policies, which, due to their implicit government guarantee, make it easier for them to obtain bank credit and have access to more abundant credit resources to support pollution expenses (Wang et al., 2022; Zhang & Zheng, 2019). On the other hand, non-state-owned enterprises (non-SOEs) face more information asymmetry with financial institutions, leading to increased financial risks associated with these enterprises and more severe credit

discrimination. Compared with SOEs, non-SOEs encounter more pronounced external financing constraints (Du et al., 2022). Consequently, the alleviation effect of DIF on financing constraints is particularly impactful within non-SOEs (L. Jin, Dai, et al., 2023); Fig. 2 (a) proves this point. Compared with SOEs, DIF is better equipped to alleviate the financing constraints faced by non-SOEs, thereby driving down their sewage discharge intensity. Mu et al. (2023) also discovered that the promoting effect of digital finance on ESG performance is more significant for non-SOEs, which is consistent with the findings of this study. This result highlights the potential of DIF development to stimulate green competitiveness among non-SOEs.

- (2) Corporate scale heterogeneity: Fig. 2 (b) shows that DIF significantly reduces the sewage discharge intensity of small and medium-sized enterprises but has no significant impact on microenterprises. In traditional financial markets, reputable

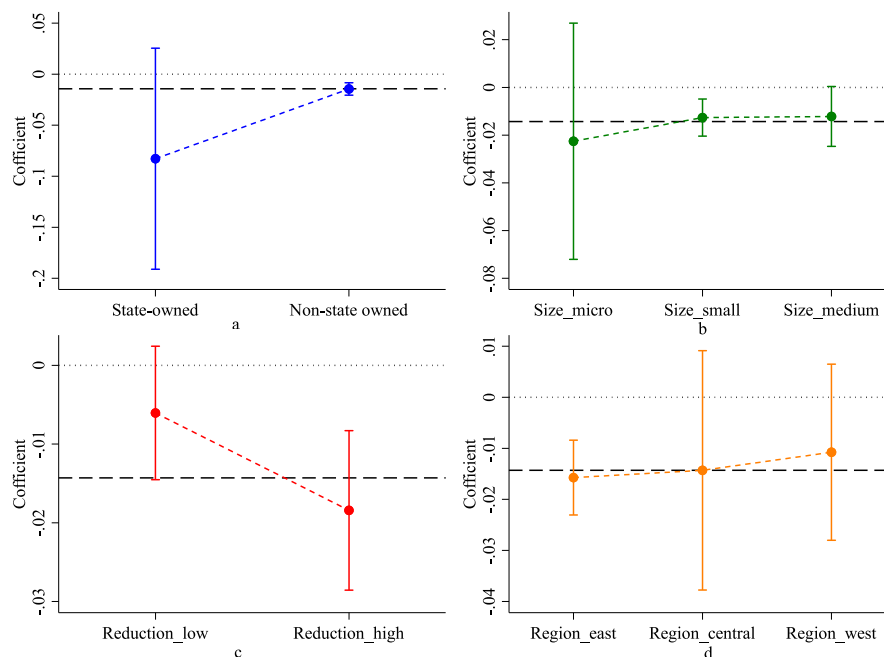


Fig. 2. Results of the heterogeneity analysis.

Notes: The samples were divided into SOEs and non-SOEs for group regression to investigate the heterogeneity of corporate ownership. The samples were divided into microenterprises, small enterprises, and medium-sized enterprises, according to Table A1, to investigate the heterogeneity of corporate scale. The samples were divided into enterprises in low-emission-reduction pressure areas and those in high-emission-reduction pressure areas to investigate regional emission reduction pressure heterogeneity, as shown in Table A3. According to the National Bureau of Statistics classification criteria, the samples were divided into enterprises in the eastern region, enterprises in the central region, and enterprises in the western region to investigate the heterogeneity of regional geographic location.

financial institutions often exclude MSMEs because of their small scale, inadequate information disclosure, and lack of effective risk management. DIF positively addresses structural deficiencies in the financial system, providing MSMEs with more convenient and flexible financing channels to support their environmental governance and green investments; however, micro-enterprises focus more on short-term benefits and profits during the operational process, resulting in a lower awareness and concern for environmental issues. Micro-enterprises typically have smaller asset sizes, weak risk resistance, relatively homogeneous operations, and high market elimination rates, and they face greater obstacles than small- and medium-sized enterprises, thus becoming more resistant to environmental investment (Tian & Lin, 2019). Despite alleviating their financing constraints, microenterprises allocate funds toward production and operations rather than environmental governance investments; hence, the effect of DIF on the environmental performance of micro-enterprises remains relatively limited. Strengthening supervision and incentives for microenterprises may help promote their environmental awareness and investment. Providing targeted training and introducing environmental requirements into financial services could guide micro-enterprises toward more sustainable operations. Fostering an encouraging environment that values environmental responsibility across all enterprise scales is critical to green transformation.

- (3) Regional emission reduction pressure heterogeneity. Since the 11th Five-Year Plan, the central government has considered various regions' primary pollutant emission levels, environmental capacity, and economic development levels to establish differentiated emission reduction targets (Xinze Li et al., 2022). As the micro-level entities responsible for pollution reduction, enterprises typically face more stringent environmental regulatory constraints in regions with higher emission reduction targets. Therefore, in regions with high emission reduction pressure, the imperative for MSMEs to undergo a green transformation becomes more pronounced, accompanied by a correspondingly vigorous demand for financing. As shown in Fig. 2 (c), DIF has a more prominent impact on enhancing environmental performance among MSMEs in regions under high emission reduction pressure. In corroboration with this study's findings, Ding et al. (2023) demonstrated that regions with more stringent environmental regulations exhibit an amplified driving effect of digital finance on green investments. Feng et al. (2022) also proposed that the proactivity of local governments toward environmental governance significantly affects the impact of DIF on green technology innovation. This result supports the notion that an integrated application of environmental governance tools and digital financial innovations can synergistically unlock the positive externalities of biotech adoption for enhanced pollution mitigation outcomes (Cao et al., 2021). The complementary mechanisms of regulatory pressure and eased financing access provide dual incentives for enterprises to upgrade their sustainability practices.
- (4) Regional geographic location heterogeneity: Economic development levels vary significantly among China's eastern, central, and western regions, exhibiting disparate degrees of digital infrastructure construction and financial advancement. The digitally advanced eastern region boasts a more refined digital infrastructure and a more mature development of DIF. Consequently, MSMEs in the eastern region can effectively leverage digital financial services to obtain funding, thereby actively engaging in green transformation and upgrading. In contrast, the central and western regions lack adequate digital infrastructure, characterized by relative economic, technological, and talent lag. As a result, the potential of DIF to empower MSMEs in facilitating green transformation remains underutilized. Fig. 2 (d) proves our

conjecture that the environmental effect of DIF is more evident in MSMEs located in the eastern region. This finding corroborates the conclusions of Hao et al. (2023) that the potential of digital finance to enhance environmental performance remains vastly underutilized in Western China. Furthermore, Sun et al. (2023) demonstrated that the carbon emission mitigation effects of DIF are more salient in eastern regions than in central and western areas. Specifically, their analysis revealed that DIF adoption decreases carbon intensity by 0.147%, 0.096%, and 0.089% for every 1% increase in eastern, central, and western provinces, respectively. These regional disparities underscore the need for differentiated DIF policies tailored to local contexts. Sophisticated digital finance ecosystems in developed eastern regions should be incentivized to harness biotech innovations to deliver green financial services and enable sustainable development. Concurrently, building digital infrastructure and promoting context-specific digital financial products could empower underdeveloped central and western regions to leverage digital finance tools to drive green industrial transitions (Hao et al., 2023). Nuanced policy measures adapted to regional variations in technological capacity and industrial composition are vital to mobilizing the transformative potential of DIF to promote equitable and sustainable development.

4.5. Mechanism test

This section validates the mechanisms by which DIF enhances the environmental performance of MSMEs. DIF aids in dissecting the predicament of financing constraints faced by MSMEs and serves as the logical starting point for this research; therefore, the first step is to examine the validity of the alleviating effect of DIF on financing constraints. Referring to Hadlock and Pierce (2010), this study uses the SA index to measure the degree of corporate financing constraints.³ Column (1) of Table 7 reports the estimated results of the effect of DIF on corporate financing constraints. The *Dif* coefficient is significantly negative at the 5 % level, denoting that DIF can effectively alleviate the financing constraints of MSMEs. This finding is consistent with the conclusions of existing research (Lu et al., 2022; J. Ouyang et al., 2023). Yu et al. (2022) discovered that financial development helps alleviate the impact of financing constraints on pollutant emission intensity. This paper further verifies whether the environmental benefits of DIF are achieved through strengthening terminal treatment, optimizing energy structure, and increasing R&D investment.

First, this paper tests whether DIF drives MSMEs to strengthen terminal treatment. In this study, the logarithm of the operating cost of sewage treatment facilities ($\ln St$) and the treatment cost of sewage treatment facilities per unit of output value ($\ln PerSt$) are used to measure the terminal treatment intensity of enterprises. Columns (2)–(3) of Table 7 show that the estimated coefficients of *Dif* are significantly positive, indicating that DIF effectively promotes corporate terminal pollution treatment. This finding is consistent with the existing research (Xu & Kim, 2022). Based on a sample of enterprises from heavily polluting industries, Ding et al. (2023) discovered that digital finance is an essential driver of corporate green investment. Due to the huge cost of emission control, whether external financing is available significantly impacts enterprises' expenditure on emission control (Bartram et al., 2022; Zhang & Zheng, 2019). DIF effectively breaks down the financing barriers for MSMEs (J. Ouyang et al., 2023), enabling them to access more credit funds to invest in pollutant treatment.

Second, this study tests whether DIF contributes to optimizing the energy consumption structure of MSMEs. Increasing the share of electric

³ $SA = -0.737 \times \text{size} + 0.043 \times \text{size}^2 - 0.04 \times \text{age}$, size represents the logarithm of the total assets of the enterprise, while age denotes the actual survival time of the enterprise.

Table 7
Mechanism test results.

Variable	Terminal treatment			Energy structure		R&D investment	
	SA-index	lnSt	lnPerSt	Ele_ratio	local	lnR&D_i	lnR&D_o
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Dif</i>	−0.003** (−2.205)	0.502*** (7.466)	0.528*** (7.461)	0.013*** (2.694)	−0.088* (−1.667)	0.004 (0.060)	0.245** (2.015)
<i>Controls</i>	Y	Y	Y	Y	Y	Y	Y
<i>Firm FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Year FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Industry-Year FE</i>	Y	Y	Y	Y	Y	Y	Y
<i>Obs</i>	45031	18008	18008	44742	12768	5448	3659
<i>adj. R²</i>	0.977	0.656	0.647	0.682	0.582	0.746	0.636

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. The t statistics are indicated in parentheses.

energy consumption can reduce pollution and boost efficiency while enhancing society's overall energy efficiency. Therefore, this study examines whether DIF can enhance the proportion of corporate electricity consumption energy consumption (*Ele_ratio*). The findings are reported in Column (4) of Table 7, showing that DIF plays a positive role in improving the proportion of corporate electricity consumption in total energy consumption. Through DIF platforms, MSMEs can expediently and flexibly acquire funding to invest in electrification transformation, thereby improving energy efficiency and fostering environmental sustainability. Furthermore, coal possesses polluting characteristics and is heavily relied upon by Chinese manufacturing enterprises. This study investigates whether DIF contributes to reducing the intensity of coal consumption (*ln coal*) by MSMEs. Column (5) of Table 7 shows that DIF significantly reduced the coal consumption intensity of MSMEs. The above findings corroborate the view that DIF can promote energy utilization efficiency and clean energy consumption (Sun et al., 2023). Based on city-level evidence, G. Li, Wu, et al. (2023) also found that digital finance can significantly increase the proportion of clean energy consumption to total energy consumption, facilitating low-carbon energy transformation. Under the impetus of DIF, MSMEs are transitioning toward cleaner and low-carbon energy consumption, thereby generating environmental benefits.

Finally, this study examines whether DIF generates environmental benefits by promoting corporate R&D investment channels. The logarithm of internal R&D expenditures (*ln R&D_i*) and the logarithm of outsourced R&D expenditures (*ln R&D_o*) are used to measure the R&D investment intensity of MSMEs. The results in Columns (6) and (7) of Table 7 denote that DIF has an insignificant impact on the internal R&D expenditures of MSMEs, while it exerts a significant facilitating effect on outsourced R&D expenditures. This outcome is consistent with the findings of Xiong et al. (2023), who showed that DIF helps promote enterprise R&D innovation and satisfies the innovative desires of risk-taking entrepreneurs. According to Lee and Min (2015), R&D investment is critical for firms to enhance their environmental performance; hence, DIF can improve the environmental performance of MSMEs by promoting R&D investment channels, mainly through the facilitation of outsourced rather than internal R&D. The principal rationale behind this is that internal R&D investment frequently entails heightened uncertainty and risk, compelling MSMEs to prioritize risk mitigation and flexibility enhancement, thus opting for outsourced R&D as the main path to innovation. O'Regan and Kling (2011) posited that enterprises with low turnover and limited R&D capabilities tend to outsource their R&D functions. Outsourcing R&D operations provides a strategic avenue for MSMEs to optimize their resource allocation, ultimately facilitating the pursuit of technological advancement and product innovation objectives.

5. Conclusions and policy implications

Among the global wave of technological revolution and the low-

carbon economy, it holds significant theoretical and practical significance to investigate whether DIF can alleviate the “difficulty in financing and high financing costs” faced by MSMEs, thus empowering them in their green and low-carbon transformation. Relying on a large sample of Chinese MSME manufacturers, this study empirically examines the effect and underlying mechanisms of DIF on the environmental performance of MSMEs. This study draws the following conclusions. First, DIF is conducive to providing financial support to MSMEs and can significantly improve their environmental performance. The sub-dimensions of DIF indicate that the coverage breadth and usage depth significantly impact the environmental performance of MSMEs. In contrast, the subdimension of digitization level has an insignificant impact. Second, heterogeneity analysis reveals that DIF has a more pronounced environmental effect for non-SOEs, small- and medium-sized enterprises, and those in areas with greater emission reduction pressure and the eastern region. Finally, this study examines the internal mechanisms of DIF to exert environmental benefits and finds that DIF can alleviate the financing constraints of MSMEs. Based on the mitigating effect of financing constraints, DIF drives MSMEs to strengthen terminal treatment, optimize energy consumption structure, and increase R&D investment, thus yielding environmental dividends. This study significantly enhances our understanding of how emerging digital financial services can empower MSMEs to transform toward greater environmental sustainability during the low-carbon transition. Granular evidence on effect heterogeneity and influence mechanisms offers tailored guidance for China's digital financial policies to promote the green development of MSMEs.

The findings of this study have several policy implications. On the one hand, the government should further strengthen the construction and popularization of digital financial infrastructure, provide convenient financial services and support for MSMEs, and actively guide MSMEs to make green investments. DIF innovations are encouraged to promote the development of environmentally friendly financial products and services applicable to MSMEs, such as green loans, carbon emissions trading, and energy management solutions, by establishing a linkage mechanism between DIF platforms and environmental policy tools to help MSMEs reduce environmental risks and costs. On the other hand, considering the heterogeneous impact of DIF on the environmental performance of MSMEs with diverse characteristics, policy-makers should contemplate developing differentiated policies for digital finance and environmental regulation to maximize the environmental benefits of DIF. China should encourage the expansion of the digital finance industry toward the central and western regions to facilitate the expansion of effective financial services in these areas.

Additionally, in regions facing significant emission reduction pressures, it is advisable to use DIF platforms to enhance the supply of green and low-carbon transition financial products and services. For MSMEs, seizing the development and transformation opportunities DIF brings is crucial. While pursuing the goals of expansion and strengthening, MSMEs should integrate their practical circumstances and strive to

enhance their competitiveness through increasing green investment, optimizing energy consumption structure, and adopting environmentally friendly production technologies.

This study has some research limitations and avenues for future research. First, due to data availability constraints, this study only examined the impact of DIF on MSMEs' environmental performance from 2013 to 2016; thus, the study period could be extended. With the future availability of more comprehensive microdata and DIF metrics, updated databases can be leveraged to evaluate their dynamic influence on enterprises' green transformation across various developmental stages. Second, this study may have omitted some critical enterprise attributes (e.g., industry categories, technology levels) and external environmental factors (e.g., marketization degrees, public environmental awareness) that may moderate how DIF affects MSMEs' environmental performance. Future research could incorporate these boundary conditions and moderators to establish a more comprehensive framework that unveils the heterogeneous effects of DIF in catalyzing green transition. Finally, this research only focused on the Chinese market, while the synergistic effects of DIF and green development in other emerging economies remain underexplored. By expanding the sample scope, future comparative studies across countries and regions could be conducted to assess the institutional and cultural origins of the

differences, thereby providing references for refining country-specific DIF policies.

CRediT authorship contribution statement

Boqiang Lin: Conceptualization, Methodology, Formal analysis, Resources, Project administration, Supervision, Writing – review & editing. **Chongchong Xu:** Conceptualization, Methodology, Formal analysis, Investigation, Software, Data curation, Visualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendixes

Table A1

Classification criteria for large, medium, small, and micro industrial enterprises

Index	Unit	Large	Medium	Small	Micro
Employees (X)	Person	$X \geq 1000$	$300 \leq X < 1000$	$20 \leq X < 300$	$X < 20$
Business income (Y)	Million yuan	$Y \geq 40000$	$2000 \leq Y < 40000$	$300 \leq Y < 2000$	$Y < 300$

Table A2

Digital inclusive finance index system

First dimension	Secondary dimension		Detailed index
Coverage breadth	Account coverage rate		Number of Alipay accounts per 10,000 people Proportion of Alipay card-bound users Average number of bank cards bound to each Alipay account
Usage depth	Payment business		Number of payments per capita Per capita payment Ratio of high-frequency active users to one or more annual active users
			Number of Yu Ebao transactions per capita Per capita Yu Ebao amount
			Amount of Internet consumer loan users per 10,000 adult user of Alipay
	Credit business	Individual users	Number of loans per capita Per capita loan amount
		Small and micro-operators	Number of users with Internet small and micro-business loans per 10,000 Alipay adult user Number of loans per household for small and micro-operators Average loan number of small and micro-operators
	Insurance business		Number of insured Alipay users per 10,000 Number of insurance transactions per capita Per capita insured
	Investment business		Number of Alipay users participating in Internet investment and financial management per 10,000 Number of investments per capita Per capita investment
	Credit investigation business		Number of life services based on credit usage per 10,000 Alipay user Per capita call times of a natural person's credit investigation
	Digitization level	Convenience	Proportion of mobile payment transactions Proportion of the mobile payment amount
		Financial service cost	Average loan interest rate for small- and micro-business operators Average personal loan interest rate

Source: Peking University Digital Financial Inclusion Index of China

Table A3

Division of high emission reduction pressure and low emission reduction pressure areas

Category	Region name
High emission reduction pressure	Beijing, Tianjin, Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Shandong, and Henan
Low emission reduction pressure	Inner Mongolia, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang

Notes: Taking the total control target of an 8% reduction of chemical oxygen demand emissions during the 12th Five-Year Plan period as the benchmark, areas exceeding this benchmark are areas with high emission reduction pressure, and those below this benchmark are areas with low emission reduction pressure.

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