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Bridging Digital Finance and ESG Success: The Role of Financing Constraints, Innovation, and Governance

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Abstract: This study investigates the impact of digital finance on corporate ESG performance, using panel data from A-share listed companies on the Shanghai and Shenzhen stock markets between 2011 and 2022. Our findings demonstrate that digital finance significantly enhances corporate ESG outcomes, with financing constraints and digital transformation serving as partial mediators and internal control quality acting as a moderating factor. The results from channel tests indicate that digital finance facilitates notable improvements in social performance and corporate governance, while its influence on environmental performance remains limited. Further analysis reveals that the positive impacts of digital finance on ESG are more evident in small-scale, technology-intensive, and non-polluting firms. This study concludes by proposing tailored recommendations for government, financial institutions, and corporations, emphasizing the need for differentiated policies to elevate ESG practices and promote higher quality, sustainable economic, and social development in China.

Keywords: digital finance; financing constraints; digital transformation; internal control quality; ESG performance



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1. Introduction

In 2004, the United Nations Environment Programme Finance Initiative (UNEPFI) published the report *Who Cares Wins*, introducing the concept of Environment, Social, and Governance (ESG) by integrating these three dimensions for the first time. After 2010, ESG evolved into a mainstream trend, with a growing number of companies adopting ESG principles and publishing annual sustainability reports (Olsen et al., 2021). Meanwhile, the quantitative ratings of corporate ESG performance by regulators and market participants have advanced considerably. Initially led by FTSE Russell, these have expanded to include a range of scoring models and rating systems, such as MSCI, Standard & Poor's, Wind, Bloomberg, and Huazheng, offering valuable references for investors. Since 2020, numerous countries have introduced and implemented ESG-related policies and regulations to promote sustainable corporate practices, including China's green finance development policy, and the EU's Sustainable Finance Disclosure Regulation (SFDR). The disclosure of non-financial information, particularly ESG metrics, underscores the protection of public interests, thereby enhancing stakeholder engagement and supporting the long-term sustainable development of both firms and society (Zheng et al., 2022). Studies have shown that higher ESG performance can substantially improve corporate value (Fatemi et al., 2018; Yoon et al., 2018; Aydoğmuş et al., 2022).

China has seen tremendous growth in digital finance in the past few years, whereas the adoption and practical application of ESG principles have not kept pace (Dollar & Huang, 2022; Steurer et al., 2024). Companies often face various challenges in implementing ESG concepts and conducting ESG practices. Paridhi et al. (2024) categorize these obstacles into three aspects: strategic level, functional level, and efficiency level. Likewise, Huiping et al. (2024) highlight the operational challenges firms face when applying the ESG framework, including inconsistent quantitative standards at the institutional level and resistance at the policy level, stakeholder conflicts, and short-term financial pressure at the company level. They further emphasize that problems such as greenwashing practices that may undermine the overall credibility and effectiveness of corporate ESG efforts, leading to pricing deviations in the capital market for corporate ESG performance and hindering the effective allocation of resources. Given its inclusive nature, digital finance can help mitigate some of these challenges. At the macro level, digital finance fosters industrial structure upgrading and regional green economic growth, optimizes resource allocation, and reduces policy and institutional resistance to ESG implementation (L. Mo et al., 2025). Additionally, digital finance eases corporate financing and governance barriers at the micro level. The former is manifested in alleviating the financial pressure on enterprises, promoting green innovation of enterprises, and releasing funds for companies to conduct relevant ESG practices (C. Chen et al., 2024), while the latter is reflected in reducing information asymmetry and providing stakeholders with real and reliable sources of information, thereby enhancing corporate governance quality, strengthening the transparency of ESG information, and improving corporate ESG disclosure (Y. Lu et al., 2022).

To address this, the State Council released a policy document entitled “Several Opinions on Strengthening Supervision, Preventing Risks, and Promoting High-Quality Development of the Capital Market” in April 2024. The 8th directive identifies five primary priorities including green finance and digital finance. The establishment of a robust sustainable information disclosure framework for publicly listed firms is also emphasized.¹ The Shanghai, Beijing, and Shenzhen stock exchanges have concurrently implemented guidelines mandating large-cap and dual-listed companies to initiate compulsory ESG-related disclosures across multiple themes beginning in 2026.² These initiatives demonstrate China’s commitment to promoting ESG integration by adapting strategies to align with national conditions and leveraging its strengths in digital finance and the wider digital economy. Thus, investigating how digital finance affects firms’ ESG outcomes in China is an essential area of research.

The contributions of this research are outlined below: Initially, limited research investigated the influence of digital finance across all aspects of ESG performance. Most existing research investigates the implications of digital finance from a macroeconomic perspective, focusing on areas such as regional economic resilience (Z. Yu et al., 2023), industrial structure upgrading (Ren et al., 2023), and economic growth (W. Wang et al., 2023). At the micro-enterprise level, empirical studies primarily explore its impact on specific ESG dimensions, including corporate green investment (Javeed et al., 2024), green technology innovation (Lin & Ma, 2022; Feng et al., 2022), financial performance (Y. Wu & Huang, 2022), and firm bankruptcy risk (Ji et al., 2022). To address this gap, our study examines not only the digital finance–ESG relationship at the micro level, but also delves deeper by decomposing the explanatory variable, digital finance, into three secondary indicators in the benchmark regression. Furthermore, in the channel test, the explained variable—enterprise ESG performance—is replaced with the performance of its three individual dimensions (i.e., E, S, and G). This approach enables us to conduct targeted analyses, thereby providing a more thorough and detailed insight into the connections among variables at the sub-dimensional level.

Second, existing studies on related topics primarily explore the mediating influence of financing constraints (Y. Mo et al., 2023; Ning & Zhang, 2023; Mu et al., 2023) and the moderating effects of political ties and the growth of regional institutions (Xue et al., 2023). By examining the mediating roles of corporate digital transformation and financing restrictions, as well as taking internal control quality into account as a moderator, we enrich the literature on the influence of digital finance on firms' ESG performance. These analyses provide a deeper understanding of the connections between core variables and the mechanisms detailing how digital finance impacts ESG outcomes.

Section 2 of this study outlines the literature and develops research hypotheses. Section 3 presents the criteria for selecting the sample, the variable definitions, and the construction of the empirical model. Section 4 analyzes and discusses the findings. Section 5 conducts additional analyses, including robustness checks, heterogeneity analysis, and endogeneity tests. Section 6 concludes and recommends relevant policies.

2. Literature Review and Hypothesis Development

2.1. Digital Finance Improves Corporate ESG Performance

As one of the world's leading economies, China commenced a new phase of economic development following the United States, marked by a transition from high-speed to medium-speed growth, with its growth drivers shifting from factor-driven to innovation-driven models. Digital finance, a landmark achievement of financial innovation in the digital economy era, embodies the incorporation of finance and digital technology. It has facilitated the deep convergence of the digital and real economies, providing fresh impetus to China's economic development.

Digital finance affects the performance of firms' ESG by influencing the three dimensions of ESG. First, environmental performance: From the macro perspective, digital finance significantly mitigates environmental inequality. It narrows regional income disparities and promotes convergence in green technology innovation capabilities, thereby reducing environmental pollution gaps between different regions (G. Li et al., 2022). At the corporate level, empirical studies confirm that digital finance substantially promotes enterprises' green innovation capabilities, leading to improved environmental performance (Feng et al., 2022; Cao et al., 2021). Second, social responsibility performance: Digital finance primarily impacts corporate social responsibility (CSR) fulfillment by its financing effects. Digital finance mitigates information asymmetry in financial markets, hence easing corporate financing constraints and enhancing access to capital. This increased financial capacity enables enterprises to allocate more resources to CSR projects (Xin et al., 2022; Han et al., 2022). Third, corporate governance performance: X. Guo et al. (2024) suggest a negative relationship between digital finance and corporate tax avoidance. In particular, digital finance mitigates tax avoidance by easing financial constraints, thereby enhancing resource allocation, and by improving the quality of corporate information, thus strengthening information governance. Additionally, a sound internal governance structure, characterized by dispersed equity and effective internal controls, along with a robust external governance environment, strengthens the impact on curbing tax avoidance. Ji et al. (2022) further demonstrate that digital finance lowers the corporate risk of bankruptcy by enhancing information transparency and lowering financial leverage, with particularly strong effects observed among smaller and higher-risk firms. This highlights digital finance's role as an external governance mechanism.

In summary, digital finance affects corporate ESG performance through multiple dimensions: First, it promotes green innovation and improves corporate environmental performance. Drawing on dynamic capability theory, enterprises must continuously innovate through internal resource reorganization and external technology absorption. Digital

finance lowers the financing threshold of green innovation projects and incentivizes enterprises for R&D innovation, thereby promoting innovation in green technology and reducing emission capabilities in the environmental dimension (W. Chen et al., 2024). Second, it eases financing constraints and improves CSR performance. According to the financing constraint theory, when internal capital is insufficient and external financing costs are high, corporate investment and R&D activities are constrained. Notably, the advancement of digital finance greatly facilitates green innovation, and also reduces the likelihood of corporate debt default by easing financing constraints. This, in turn, frees up financial resources for CSR-related expenditures including employee welfare and community development (Cui, 2025). Third, it reduces information asymmetry and improves the performance of corporate governance. Information asymmetry theory posits that limited and unequal access to information increases capital financing and monitoring costs for firms. Additionally, digital finance has been linked to improvements in information transparency and a reduction in agency problems, thereby strengthening corporate governance performance (Kong et al., 2022; Sun et al., 2023).

Based on the above discussion, we propose the first hypothesis:

H1. *Digital finance affects a firm's ESG performance across multiple dimensions, leading to an overall improvement in performance.*

2.2. *By Reducing the Company's Financial Restrictions, Digital Finance Contributes to Improve ESG Performance*

Several non-financial publicly listed Chinese companies identify financing constraints as the main obstacle to further advancement (Claessens & Tzioumis, 2006). Other studies also show that previous financial reforms imposed stricter budget constraints on large enterprises, particularly state-owned enterprises, through stricter market discipline (Y. Huang & Ge, 2019). However, because the reform only included a moderate amount of financial liberalization, small and medium-sized businesses (also known as SMEs) have not significantly benefited, leaving their financing constraints largely unaddressed (K. S. Chan et al., 2012).

Financing constraints adversely affect corporate social responsibility (CSR) activities. Enterprises tend to weigh their financial conditions and economic environment before engaging in CSR initiatives. Firms facing severe financing constraints are less likely to participate in CSR practices, as resource limitations restrict their capacity to allocate funds toward non-essential activities (C. Y. Chan et al., 2017). Additionally, some studies highlight the growing challenge investors face in identifying investments aligned with appropriate ESG policies, as firms may engage in greenwashing by providing misleading ESG disclosures (T. Li et al., 2024; Deng et al., 2024). Greenwashing behavior is often driven by financial constraints, with the financial environment playing a key role in its prevalence. For instance, companies with high leverage may experience increased financial pressures, prompting a greater likelihood of greenwashing (D. Zhang, 2022). Thus, severe financing constraints hinder companies from actively participating in ESG practices and fulfilling their associated responsibilities. Such constraints increase the likelihood of companies straying from the fundamental principles of the ESG framework, potentially misleading stakeholders, including investors, and compromising the reliability of ESG disclosures and the assessment of the firm's ESG performance.

Digital finance, characterized by its inclusivity and digital nature, can substantially improve business financing and lower financing costs via two approaches (C. Li et al., 2023; Y. Mo et al., 2023). First, digital finance creates an efficient path for information transmission among financial institutions, hence improving the accuracy and accessibility of business information. This, in turn, helps mitigate potential costs associated with adverse selection.

Second, digital finance alleviates financial frictions between the securities market and the credit market, thereby reducing market transaction costs and improving enterprises' external financing capacity. Together, these mechanisms effectively mitigate financing constraints, enabling enterprises to access financial resources more efficiently. In view of this, Hypothesis 2 is proposed as follows:

H2. *Digital finance indirectly improves corporate ESG performance by mitigating firms' financing constraints.*

2.3. Digital Finance Facilitates a Firm's Digital Transformation, Thereby Indirectly Enhancing Corporate ESG Performance

China's digital economy is experiencing rapid growth, with technological innovation—particularly in information and digital technology—providing fresh impetus to its economic development (Kharas & Kohli, 2011). With a strong emphasis on the necessity to “speed up corporate digital transformation and upgradation”, the State Council of China announced its fourteenth five-year plan for the development of the digital economy. Within this context, digital finance and digital transformation are two frequently discussed concepts. The former primarily reflects the macro-level development of the financial sector, while the latter represents the micro-level manifestation of digital economic progress within enterprises (T. Li et al., 2022).

Digital transformation refers to business transformation driven by emerging technologies, offering significant potential for revenue growth and cost savings. Through this process, enterprises can leverage technologies to achieve comprehensive digitalization and organizational transformation, fostering enhanced development and competitiveness (Tang, 2021).

The existing literature indicates that digital transformation is essential for enterprises in attaining sustainable development, with digital finance significantly contributing to this change (X. Liu et al., 2023; S. Wang & Esperança, 2023; Luo, 2022; M. Yu & Yan, 2022). From a resource allocation perspective, the value created by enterprise digitalization extends beyond economic gains to encompass social and environmental benefits. Specifically, by improving internal information accessibility, reducing management lack of vision, and bolstering technology innovation skills, digital transformation can significantly improve the ESG outcomes of a company (Zhong et al., 2023). Digital transformation can promote corporate ESG outcomes in three ways: increasing operational management efficiency, optimizing human capital structures, and fostering green innovation. However, the impact varies depending on factors such as the firm's capital intensity, sophistication in technology, and carbon emission rates, highlighting its heterogeneous effects across different organizational contexts (Peng et al., 2023). As such, we propose Hypothesis 3 as follows:

H3. *Digital finance indirectly enhances corporate ESG performance by driving corporate digital transformation.*

2.4. Internal Control Quality Positively Moderates the Influence of Digital Finance on the Firm's ESG Performance

Since the introduction of the “Basic Standards for Enterprise Internal Control” in 2008, Chinese regulators have consistently emphasized the importance of internal control construction among listed companies. In recent years, the growing adoption of ESG principles has prompted updates and enhancements to regulatory requirements to better align with these evolving standards (Singhania & Saini, 2022; S. Lu & Cheng, 2023). In practice, internal control construction and ESG performance are not separate processes but rather an integrated and unified framework. Companies should view ESG ratings and internal

control system investments as strategic tools for enhancing corporate value. By allocating resources effectively to internal control activities, firms can address ESG issues more comprehensively and create long-term value. Internal control serves as the foundational safeguard for successful ESG integration, ensuring that ESG considerations are embedded into organizational practices and decision-making (Harasheh & Provasi, 2023).

Empirical studies demonstrate that internal control quality positively affects ESG outcomes, indicating that robust internal governance strengthens a firm's sustainability initiatives (Koo & Ki, 2020; Yan et al., 2024). Enhanced ESG performance signifies ethical decision-making and financial resilience, reinforcing a firm's internal control framework (Moffitt et al., 2024). The positive relationship can be attributed to two reasons. First, ESG principles emphasize long-term enterprise sustainability, aligning closely with the goals of internal control systems. Adopting an internal control model that integrates sustainable development with ESG objectives enhances the effectiveness and long-term development of corporate operations (S. Li et al., 2022). Second, effective internal control fosters conditions that improve corporate ESG performance. These include enhancing governance structures to mitigate agency conflicts which mainly occur between management and investors (Bertrand & Mullainathan, 2003), providing timely risk feedback, response, and risk prevention (Bargeron et al., 2010), optimizing corporate capital efficiency (Dong & Gou, 2010), encouraging corporate innovation (K. C. Chan et al., 2021), and improving corporate social responsibility initiatives (X. Li, 2020). Consequently, the digital finance–ESG relationship may be moderated by the quality of internal control. Considering the prior discussions, Hypothesis 4 is proposed:

H4. *Internal control quality positively moderates the digital finance–ESG relationship.*

3. Methodology and Data

3.1. Sample

Our analysis utilizes data from A-share firms listed on the Shanghai and Shenzhen stock exchanges in China, spanning the period from 2011 to 2022. We select 2011 as the starting year since it marks the initial release of the Digital Inclusive Finance Index. To enhance the robustness of the results and align with standard research practices, the sample is refined as follows: (1) Firms in the financial sector are excluded. (2) Companies with unusual trading status (which are usually identified as ST, *ST, and PT) are removed. (3) Observations with missing key variables are omitted. (4) All continuous variables are winsorized by 1% at both tails to mitigate the influence of outliers. After these adjustments, 25,800 firm-year observations are retained. The primary data sources are as follows: (1) ESG rating data from the Bloomberg and Wind databases. (2) Digital finance data from the DFII-PKU compiled by Peking University (see details in Section 3.2.2). (3) Other financial data are derived from the CSMAR and WIND databases.

3.2. Variables

3.2.1. Explained Variable: Corporate ESG Performance (ESG)

This study evaluates corporate ESG performance using the Huazheng ESG rating. Following Q. Huang et al. (2023), we adopt the Huazheng ESG rating, which assigns values from 1 to 9, corresponding to ratings from “C” to “AAA”.³ Since the database updates ESG performance ratings quarterly, the annual average of these assigned quarterly ratings is used to construct the explanatory variable. Better ESG performance for the specified year is signified by a higher value.

3.2.2. Explanatory Variable: Digital Finance (DF)

There are two primary approaches to measuring the progress of digital finance when the study is limited to China. The first method involves using the Baidu News Database to count the frequency of key terms associated with digital finance (Zuo et al., 2023; Razzaq & Yang, 2023). However, this approach remains subjective due to the absence of standardized criteria for keyword selection. The second method utilizes the DFII-PKU (F. Guo et al., 2020) that offers a more robust and comprehensive measure, encompassing multi-level data (at the provincial level, city level, and county level) in China from 2011 to 2022. The DFII-PKU index also captures the development of digital finance across three aspects: usage depth, degree of digitalization, and coverage breadth. These dimensions provide a multidimensional perspective on China's advancements in digital finance. Given its objectivity and comprehensiveness, this study adopts the second method, using the DFII-PKU at the city level as the measure. To ensure consistency with other variables, all digital finance index values are divided by 100.

3.2.3. Mediators

Financing Constraints (WW Index)

We assess the financial restrictions that businesses confront using the WW index, which was developed by Whited and Wu (2006). This indicator is particularly suitable for assessing Chinese companies, given the unique characteristics of China's capital market compared to other countries and regions (C. Li et al., 2023).

Corporate Digital Transformation (CDT)

Two approaches are commonly employed to assess the degree of digital transformation in enterprises. First, a dummy variable method is used to assign a value of 1 if the enterprise has gone through digital transformation during the year, and 0 otherwise (Q. Zhang & Yang, 2023). Second, a text analysis method is used to analyze the frequency of key terms associated with digital transformation in the listed firm's annual reports and logarithmic processing is applied to the results (F. Wu et al., 2021). Given the simplicity and ambiguity of the first method, this study adopts the second approach that provides a more nuanced measure, capturing variations in the extent of digital transformation across firms and over time. The key phrases identified through this method fall into five categories: four types of digital technologies, namely, cloud computing, blockchain, artificial intelligence, and big data, as well as a separate category for the application of digital technology. Then, add 1 to the outcome and apply logarithmic processing to generate the CDT. A lower CDT value signifies a reduced level of digital transformation within the enterprise.

3.2.4. Moderator: Internal Control Quality (ICQ)

Following X. Li et al. (2018) and X. Wang et al. (2021), this study employs the internal control index score from the Dibo database (DIB) to measure the ICQ. The index is compiled based on the COSO framework and adheres to both domestic and international standards, including those of the China Securities Regulatory Commission, making it particularly suited to assessing the internal control quality of Chinese enterprises. To ensure consistency in magnitude with other variables, all internal control index scores are divided by 1000.

3.2.5. Control Variables

We incorporate control variables related to firm characteristics, corporate governance, and regional economic development to reduce the influence of omitted variables on causal inference. It should be noted that the variable *Findev* is controlled to reflect the impact of

the traditional financial sector (Y. Wu & Huang, 2022). The summary of all the variables is detailed in Table A1 of Appendix A.

3.3. Empirical Model

We use the following models to investigate how digital inclusive finance affects corporate ESG performance:

$$ESG_{i,t} = \alpha_0 + \alpha_1 DF_{m,t} + \alpha_2 Controls_{i,t} + Year_t + Industry_n + \varepsilon_{i,t} \quad (1)$$

$$Mediator_{i,t} = \beta_0 + \beta_1 DF_{m,t} + \beta_2 Controls_{i,t} + Year_t + Industry_n + \varepsilon_{i,t} \quad (2)$$

$$ESG_{i,t} = \gamma_0 + \gamma_1 DF_{m,t} + \gamma_2 Mediator_{i,t} + \gamma_3 Controls_{i,t} + Year_t + Industry_n + \varepsilon_{i,t} \quad (3)$$

$$ESG_{i,t} = \varphi_0 + \varphi_1 DF_{m,t} + \varphi_2 Moderator_{i,t} + \varphi_3 DF_{m,t} \times Moderator_{i,t} + \varphi_4 Controls_{i,t} + Year_t + Industry_n + \varepsilon_{i,t} \quad (4)$$

Equation (1) serves as the benchmark model, while Equations (2) and (3) are models for testing mediators, constructed based on the work of Wen and Ye (2014), and Equation (4) is the model for the moderating effect test. In these models, the explained variable denotes corporate ESG performance $ESG_{i,t}$, the main explanatory variable is the digital inclusive finance $DF_{m,t}$ (m represents the city where the firm i is located), $Mediator_{i,t}$ and $Moderator_{i,t}$ are the aforementioned mediating variables and moderating variables, the control variables include the aforementioned control variables $Controls_{i,t}$, $Year_t$ represents time fixed effects, $Industry_n$ denotes industry fixed effects (n represents the industry where the firm i belongs), and $\varepsilon_{i,t}$ is an error term. Clustered standard errors at the city level are applied to ensure robust estimation.

4. Results and Discussion

4.1. Descriptive Statistics

The descriptive statistics for all variables are presented in Table 1. The mean and median of ESG (with a value of 4.145 and 4, respectively) suggest that listed Chinese companies have partially implemented ESG principles and achieve modest performance levels, with most companies scoring below the fifth level (i.e., “BB” rating). The standard deviation of ESG is 0.951, with a range from 1 to 8, indicating notable variation in ESG performance across companies. Regarding the explanatory variable DF, its values range from 0.566 to 3.597, with a standard deviation of 0.811, reflecting significant regional disparities in digital finance development. Similarly, the three secondary indicators (i.e., Cov, Dep, and Dig) exhibit statistical characteristics analogous to DF. Additionally, the development levels of traditional financial models, as measured by Findev, also vary considerably across provinces.

The statistics of the mediating variable WW (i.e., mean, minimum value, maximum value, and median) show negative values, showing that all listed Chinese companies face a certain level of financing constraints, with substantial variations in the severity of these constraints across firms as indicated by its standard deviation of 0.073. Another mediator CDT exhibits a mean of 1.444 and a standard deviation of 1.415, with values ranging from 0 to 5.037. The results suggest that, in the context of the fast progress of China’s digital economy, most companies have pursued a certain level of digital transformation to align with this mainstream trend, though the extent of transformation varies significantly among firms. Given that the ICQ variable’s standard deviation is 0.127, it is evident that various businesses have varying levels of internal control quality.

Table A2 in Appendix A summarizes the correlation analysis results.

Table 1. Descriptive statistics.

VarName	Obs	Mean	SD	Min	Median	Max
ESG	25,800	4.145	0.951	1.000	4.000	8.000
DF	25,800	2.370	0.811	0.566	2.469	3.597
Cov	25,800	2.415	0.853	0.572	2.441	3.825
Dep	25,800	2.258	0.766	0.553	2.432	3.500
Dig	25,800	2.424	0.879	0.219	2.687	3.365
CDT	25,800	1.444	1.415	0.000	1.099	5.037
WW	25,800	−1.021	0.073	−1.230	−1.018	−0.856
ICQ	25,800	0.640	0.127	0.000	0.664	0.835
Age	25,800	2.234	0.772	0.693	2.398	3.367
Size	25,800	22.406	1.310	20.056	22.212	26.413
Lev	25,800	0.447	0.201	0.060	0.444	0.896
ROA	25,800	0.038	0.061	−0.211	0.036	0.216
TobinQ	25,800	1.989	1.264	0.834	1.573	8.114
Growth	25,800	0.165	0.390	−0.537	0.104	2.354
Board	25,800	2.129	0.198	1.609	2.197	2.708
Indep	25,800	0.376	0.054	0.333	0.364	0.571
Top1	25,800	0.345	0.149	0.091	0.321	0.743
Dual	25,800	0.265	0.442	0.000	0.000	1.000
Big4	25,800	0.068	0.251	0.000	0.000	1.000
SOE	25,800	0.397	0.489	0.000	0.000	1.000
Inst	25,800	0.460	0.247	0.004	0.478	0.934
Findev	25,800	3.851	1.441	1.829	3.463	7.605
GDP	25,800	9.007	1.102	6.242	9.128	10.707

4.2. Baseline Regression Results

Table 2 illustrates the effect of digital financial development on the firm's ESG performance. M(1) serves as the baseline regression, excluding control variables. Across all models (i.e., M(1) to M(5)), the results consistently indicate that digital financial development significantly enhances corporate ESG performance. Hence, H1 is verified. Specifically, DF exhibits the strongest influence on ESG, with a coefficient of 0.496 in M(2) compared to M(1), indicating that its impact on ESG becomes more pronounced after including control variables. Among the three secondary indicators, Dep exhibits the most substantial impact on ESG performance, with a coefficient of 0.456, suggesting that the depth of DFII-PKU usage plays a significant role in shaping corporate ESG outcomes. The empirical results confirm the synergistic effects of the aforementioned influencing channels. First, the expansion in the breadth of digital finance coverage improves the accessibility to financial services, thereby alleviating financing constraints and freeing up corporate resources for investment in social responsibility initiatives. Second, the deep integration of digital technologies reduces information asymmetry and strengthens corporate governance through high-frequency data interaction and other mechanisms. Third, digital technologies facilitate green innovation, contributing to the optimization of environmental performance.

Table 2. Basic regression results.

	(M1)	(M2)	(M3)	(M4)	(M5)
	ESG	ESG	ESG	ESG	ESG
DF	0.452 *** (5.127)	0.496 *** (5.384)			
Cov			0.259 *** (2.952)		
Dep				0.456 *** (5.868)	

Table 2. Cont.

	(M1)	(M2)	(M3)	(M4)	(M5)
	ESG	ESG	ESG	ESG	ESG
Dig					0.141 *** (2.678)
Age		−0.243 *** (−15.819)	−0.245 *** (−15.567)	−0.243 *** (−16.506)	−0.245 *** (−15.573)
Size		0.288 *** (26.193)	0.288 *** (25.918)	0.289 *** (26.837)	0.288 *** (26.109)
Lev		−0.901 *** (−16.753)	−0.900 *** (−16.632)	−0.889 *** (−16.665)	−0.895 *** (−16.823)
ROA		1.908 *** (10.558)	1.923 *** (10.614)	1.884 *** (10.544)	1.949 *** (10.981)
TobinQ		−0.008 (−0.845)	−0.008 (−0.846)	−0.008 (−0.841)	−0.008 (−0.849)
Growth		−0.133 *** (−7.995)	−0.134 *** (−8.068)	−0.130 *** (−8.095)	−0.134 *** (−8.144)
Board		0.122 * (1.819)	0.118 * (1.750)	0.126 * (1.861)	0.113 (1.644)
Indep		1.578 *** (7.198)	1.567 *** (7.058)	1.602 *** (7.349)	1.558 *** (6.946)
Top1		0.014 (0.186)	0.014 (0.182)	0.023 (0.306)	0.026 (0.339)
Dual		−0.032 (−1.596)	−0.031 (−1.524)	−0.031 (−1.523)	−0.028 (−1.370)
Big4		0.059 (1.380)	0.060 (1.386)	0.053 (1.258)	0.058 (1.317)
SOE		0.238 *** (7.672)	0.231 *** (7.367)	0.244 *** (7.813)	0.221 *** (6.937)
Inst		−0.137 *** (−2.987)	−0.135 *** (−2.919)	−0.140 *** (−3.058)	−0.138 *** (−2.971)
Findev		−0.000 (−0.030)	0.003 (0.276)	−0.008 (−0.713)	0.003 (0.299)
GDP		−0.056 ** (−2.511)	−0.031 (−1.276)	−0.050 *** (−2.596)	0.013 (0.748)
_cons	3.060 *** (28.523)	−2.948 *** (−9.607)	−3.009 *** (−9.491)	−2.940 *** (−9.667)	−3.188 *** (−10.365)
YEAR	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes
N	25,800	25,800	25,800	25,800	25,800
R ²	0.081	0.243	0.240	0.245	0.239

Notes: M(1), M(2), M(3), M(4), and M(5) are estimated using fixed-effect models. ***, **, and * denote significance at the 1%, 5%, and 10% level, with t-values in parentheses.

4.3. Mediating and Moderating Effect

Table 3 presents the mediation analyses (M(1) to M(4)) and the moderation analysis (M(5)). M(1) and M(2) assess the mediating impact of financing constraints on the digital finance–ESG relationship. The findings suggest that digital finance significantly eases financing constraints, as evidenced by a negative coefficient of -0.006 . In M(2), WW exhibits a negative and significant association with ESG performance, while DF maintains a positive and statistically significant relationship. These results indicate that digital finance indirectly enhances corporate ESG performance by easing financing constraints. Notably, the coefficient for DF on ESG declines from 0.496 (see M(2) in Table 2) to 0.480 (see M(2) in Table 3) when financing constraints are considered, confirming a partial mediating effect. The findings align with Y. Mo et al. (2023), reinforcing the intermediary role of financing constraints.

Table 3. Mediation and moderation tests.

	M(1)	M(2)	M(3)	M(4)	M(5)
	WW	ESG	CDT	ESG	ESG
DF	−0.006 ** (−2.287)	0.480 *** (5.177)	0.415 *** (3.344)	0.481 *** (5.101)	0.471 *** (5.367)
WW		−2.445 *** (−9.989)			
CDT				0.036 *** (3.613)	
ICQ					0.939 *** (12.855)
ICQ×DF					0.370 *** (4.878)
_cons	0.067 *** (6.846)	−2.784 *** (−9.169)	−4.515 *** (−8.303)	−2.786 *** (−9.078)	−3.140 *** (−10.762)
CONTROL	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes
N	25,800	25,800	25,800	25,800	25,800
R ²	0.854	0.248	0.495	0.244	0.257

Notes: M(1), M(2), M(3), M(4), and M(5) are estimated using fixed-effect models. ***, ** denote significance at the 1% and 5% level, with t-values in parentheses.

M(3) and M(4) investigate the mediating influence of corporate digital transformation on the digital finance–ESG relationship. In M(3), digital finance significantly enhances digital transformation, evidenced by a coefficient of 0.415. In M(4), both CDT and DF exhibit positive and statistically significant effects on ESG performance, demonstrating a greater digital transformation contributes to improved ESG outcomes. Consistent with the results observed for financing constraints, the reduced magnitude of digital finance’s effect on ESG outcomes is observed after accounting for corporate digital transformation, confirming its partial mediating role in this relationship.

M(5) demonstrates the moderating impact of internal control quality on the digital finance–ESG relationship. The interaction term (ICQ × DF) is positive and significant, with a coefficient of 0.37, reflecting that stronger internal control quality amplifies the positive effect of digital finance on a firm’s ESG outcomes. This implies that the effectiveness of digital finance in promoting ESG outcomes is amplified when firms exhibit a strong internal control system.

The mediation and moderating analyses provide compelling evidence that digital finance influences corporate ESG performance through multiple pathways, including alleviating financing constraints, reducing information asymmetry, and fostering green innovation. The financing constraint channel primarily enhances the environmental and social responsibility dimensions by enabling enterprises to access sufficient capital for green innovation and to reallocate freed-up resources toward ESG-related initiatives, particularly in the realm of social responsibility. The information transparency channel predominantly affects corporate governance, as digital finance transformation facilitates greater transparency in information disclosure, thereby mitigating information asymmetry and enhancing governance structures. Meanwhile, robust internal control systems serve as reinforcing mechanism across these channels. Efficient internal controls reduce the likelihood of fraud and misreporting, ensuring the proper allocation of green innovation funds (green technology innovation channel), regulating the use of social responsibility resources (financing constraint channel), and improving the credibility and accuracy of ESG disclosures (information transparency channel). Hence, internal control quality amplifies the positive impact of digital finance on overall ESG performance.

5. Further Research: Heterogeneity Analysis

5.1. Robustness Test

Three robustness tests were conducted to validate the consistency of our findings: substituting the explained variable, replacing the explanatory variable, and excluding samples that could potentially bias the findings.

5.1.1. Substituting the Explained Variable

In the benchmark regression analysis, the Huazheng ESG rating was employed to evaluate corporate ESG performance. However, variations in evaluation systems and standards among rating agencies may affect the results. To address this concern, we performed a robustness check by substituting the Huazheng ESG rating with the Bloomberg ESG rating, as presented in M(1) of Table 4. Notably, the findings remain robust, demonstrating that our findings are insensitive to the choice of ESG performance measure.

Table 4. Robustness test.

	M(1)	M(2)	M(3)	M(4)
	ESG_Bloomberg	ESG	ESG	ESG
DF	0.030 *** (3.204)			0.482 *** (5.200)
DF_province		0.399 *** (5.034)		
DF_county			0.905 *** (4.481)	
_cons	−0.357 *** (−8.118)	−2.924 *** (−7.491)	−3.606 *** (−9.339)	−2.981 *** (−9.638)
CONTROL	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes
N	9814	25,800	15,871	23,785
R ²	0.646	0.244	0.248	0.242

Notes: M(1), M(2), M(3), and M(4) are estimated using fixed-effect models. ***, denote significance at the 1% level, with t-values in parentheses.

5.1.2. Substitution of the Explanatory Variable

The benchmark regression analysis applied the city-level DFII-PKU to assess the development of digital finance. To ensure robustness, we employed a provincial-level indicator and further refined it to the county level, while appropriately adjusting the cluster standard error. Given the availability of county-level data solely from 2014, the sample interval and the number of observations were adjusted. The regression outcomes in M(2) and M(3) of Table 4 validate the assumptions and demonstrate the robustness of the conclusions.

5.1.3. Excluding Partial Data to Avoid Possible Influencing Factors

In light of China's implementation of various Internet finance policies in 2015 and the occurrence of two significant stock market fluctuations that year, which impacted numerous listed companies and potentially influenced their ESG performance, this analysis excludes the data from 2015. The results of M(4) in Table 4 indicate that the conclusions remain robust.

5.2. Endogeneity Test

Two methods were applied to solve potential endogeneity problems. First, we started with lagging the dependent variable ESG by one period in the regression and denoted it as f.ESG. This approach mitigates potential bidirectional causality between the independent

variable (DF) and the dependent variable (ESG). The regression results in M(1) of Table 5 indicate that the conclusions are robust.

Given that the first method alone cannot fully eliminate endogeneity, an instrumental variable (lagging the DFII-PKU index by one period and denoting it as L.DF) was employed to further address endogeneity concerns. This choice is justified as the previous state of digital financial development correlates with current digital financial development but lacks a direct causal relationship with current ESG performance, thereby meeting the relevance and exogeneity criteria for the selection of instrumental variables. Furthermore, the Kleibergen–Paap rk LM and Wald F statistics, along with the Hansen test, confirmed the absence of weak instruments or identification issues, thereby validating the robustness of the instrumental variable selection.

M(2) of Table 5 reports the findings of the two-stage least squares regression analysis. In the first stage (M(2)_Stage 1), the instrumented variable L.DF shows a significant and positive coefficient, confirming its relevance. In the second stage (M(2)_Stage 2), the coefficient on DF remains significantly positive at the 1% level, suggesting that digital financial development significantly improves corporate ESG outcomes. These results confirm the robustness of the baseline findings.

To further mitigate endogeneity concerns and reinforce the robustness of our conclusions, we incorporated the lagged dependent variable (ESG) into the baseline model (Equation (1)) and performed a robustness test using the two-step system GMM method within a dynamic panel framework (Equation (5)) outlined below, applying robust standard errors to $\varepsilon_{i,t}$.

$$ESG_{i,t} = \eta_0 + \eta_1 ESG_{i,t-1} + \eta_2 DF_{m,t} + \eta_3 Controls_{i,t} + Year_t + Industry_n + \varepsilon_{i,t} \quad (5)$$

M(3) of Table 5 confirms the robustness of our findings. The sample passed the autocorrelation test (AR Test), and the Hansen test revealed no over-identification issues. Furthermore, both the lagged ESG performance of enterprises (L.ESG) and digital finance (DF) exhibited a significant positive effect on current ESG performance.

Table 5. Endogeneity test.

	M(1)	M(2)_Stage 1	M(2)_Stage 2	M(3)
	f.ESG	DF	ESG	ESG
L.DF		0.943 *** (48.373)		
DF	0.491 *** (5.064)		0.537 *** (5.346)	0.850 ** (2.23)
L.ESG				0.503 *** (38.74)
Kleibergen–Paap rk LM				
p-value			0.000	
Kleibergen–Paap rk Wald F			2339.96	
statistic				
AR(1) Test				0.000
AR(2) Test				0.307
Hansen Test			0.000	0.637
_cons	−3.071 *** (−9.400)	0.349 *** (17.137)	−3.303 *** (−10.090)	−1.249 (−1.49)
CONTROL	YES	YES	YES	YES
YEAR	YES	YES	YES	YES
INDUSTRY	YES	YES	YES	YES
N	20,285	20,285	20,285	20,285
R ²	0.255	0.996	0.247	–

Notes: M(1) and M(2) are estimated using fixed-effect models. M(3) is estimated using a two-step system GMM method within a dynamic panel framework. ***, ** denote significance at the 1% and 5% level, with t-values in parentheses.

5.3. Heterogeneity Test

The empirical findings presented earlier suggest that digital finance significantly enhances corporate ESG performance. However, the extent to which this impact varies across enterprises with different characteristics requires further investigation. This section examines the varied impacts of digital finance on corporate ESG development by considering firm size, environmental pollution levels, and production factor density.

5.3.1. Analysis of Firm Size

We categorized corporates as large or small enterprises based on the median enterprise scale, constructing a binary variable, SIZE (1 is assigned to small enterprises below the median scale, while 0 is given for large enterprises). The interaction term between SIZE and DF (SIZE_DF) was then incorporated into the benchmark regression for empirical testing. It can be inferred that digital finance has a greater impact on enhancing ESG performance for small businesses, which is supported by the results (the significantly positive coefficient of SIZE_DF and ESG) displayed in M(1) of Table 6.

Table 6. Heterogeneity test.

	M(1)	M(2)	M(3)
	ESG	ESG	ESG
DF	0.468 *** (5.092)	0.510 *** (5.519)	0.462 *** (4.860)
SIZE_DF	0.057 *** (2.771)		
Pollute_DF		−0.084 *** (−3.511)	
Techintensive_DF			0.061 *** (2.602)
_cons	−3.252 *** (−8.559)	−2.995 *** (−9.809)	−2.904 *** (−9.538)
CONTROL	Yes	Yes	Yes
YEAR	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes
N	25,800	25,800	25,800
R ²	0.244	0.244	0.243

Notes: M(1), M(2), and M(3) are estimated using fixed-effect models. *** denote significance at the 1% level, with t-values in parentheses.

The heterogeneity is attributed to two reasons. First, small enterprises generally face greater financial constraints and weaker financial strength compared to large firms. They often encounter higher barriers to securing traditional bank loans and other forms of financing. Consequently, the inclusive nature of digital finance can more effectively and promptly alleviate their funding needs, as suggested by [Luo et al. \(2018\)](#). Second, small enterprises typically have shorter operational histories, lower market share, and less established reputations compared to larger firms. From a managerial perspective, executives in small enterprises may prioritize improving ESG performance to enhance corporate reputation and build a positive image, as noted by [Daromes et al. \(2022\)](#).

5.3.2. Analysis of Corporate Environmental Pollution Degree

The ESG concept encompasses how companies manage environmental impact, and the degree of its impact may vary across industries due to different company characteristics. We categorize sample companies as polluting or non-polluting to assess the differential impact of digital finance on the corporate ESG outcomes concerning environmental pollution.⁴ A

dummy variable (Pollute, assigned a value of 1 for polluting companies and 0 otherwise) is constructed for the regression analysis.⁵

As shown in M(2) in Table 6, DF has a positive coefficient, while the interaction term Pollute_DF displays a negative coefficient; both are statistically significant at the 1% level. These results suggest that digital finance exerts a greater impact on enhancing ESG outcomes in non-polluting enterprises relative to heavily polluting industries. This disparity could arise due to the substitutability between green and non-green technologies. Heavily polluting industries often rely on the initial productivity advantages and market scale effects of non-green technologies, reducing their incentive to adopt green innovations.

Additionally, the fact that industries rely on conventional manufacturing approaches with high energy consumption and significant pollution reduces the effectiveness of digital finance in enhancing ESG outcomes for such industries compared to non-polluting enterprises (Acemoglu et al., 2012; J. R. Wang & Zhang, 2018).

5.3.3. Analysis of Intensity of Enterprise Production Factors

Technological development and innovation, digital finance, and corporate ESG performance are closely interconnected. Following Yin et al. (2018), we categorize enterprises as technology-intensive or non-technology-intensive according to production factor intensity. Technology-intensive enterprises are identified by specific industry codes and are characterized by a low proportion of fixed assets, higher R&D expenditure, and salary levels, with technology playing a more critical role than capital or labor.⁶ A dummy variable (Techintensive) is constructed for the regression analysis.

Based on the findings of M(3) in Table 6, digital finance exerts a more pronounced impact on ESG outcomes for technology-intensive enterprises relative to non-technology-intensive ones, as evidenced by the positive and statistically significant coefficients for DF and the interaction term Techintensive_DF at the 1% level. The heterogeneity likely stems from the unique characteristics of technology-intensive firms, which typically possess extensive professional talent and R&D teams. These enterprises prioritize innovation, emphasizing the role of knowledge and technology in production and operations. Empirical studies show that technological advancements positively impact the three components of ESG—environmental, social, and governance factors (see, inter alia, Truant et al., 2023; Broadstock et al., 2021). Consequently, technology-intensive firms are better positioned and motivated to leverage digital finance, capitalize on their technological advantages, engage in activities like green technology innovation, and enhance ESG performance.

To accurately assess the impact of industry heterogeneity, we incorporated interaction terms between industry dummy variables and digital finance into the benchmark model for further analysis, with a specific focus on the impact of industry characteristics on enterprise ESG performance. The corresponding results are presented in Table A3 of Appendix A. Meanwhile, Table A4 in Appendix A lists all industry codes for polluting and technology-intensive enterprises, along with their respective definitions and interpretations.

The results show that in the context of digital finance influencing corporate ESG performance, a significant positive causal relationship exists for certain industries, particularly those characterized as polluting or technology-intensive. This suggests that industry-specific characteristics and backgrounds warrant closer attention. For example, the non-metallic mineral mining industry (industry code: B10) exhibits a significantly negative coefficient. This may be attributed to the sector's economic orientation, which tends to prioritize short-term profitability over long-term ESG investment. As non-metallic mineral products (e.g., sand, gravel, and clay) are generally low-value-added resources, companies in this sector are more inclined to focus on cost control rather than sustainability (C. Wang et al., 2024). Moreover, the development of digital finance may inadvertently

reinforce the high-pollution, high-energy-consumption production models typical of such enterprises (Rigobon, 2024).

Additionally, the improvement of ESG performance for certain enterprises appears to be driven more by firm-level or macro-level factors rather than the industry-level characteristics. For instance, in the postal industry (industry code: G60), while firms may have integrated digital technologies into business management and operational processes, their core services such as parcel delivery and traditional postal operations still rely heavily on physical infrastructure and conventional financial settlement systems. As a result, these enterprises may prioritize logistics efficiency over financial innovation or ESG, which may explain the insignificant regression results observed for this sector (Dobrodolac et al., 2018).

The heterogeneity analysis further underscores the contextual dependence of the underlying transmission channels. Small-scale enterprises, constrained by limited access to external financing, rely more heavily on the alleviation of financing constraints. Non-polluting enterprises, facing lower environmental compliance risks, benefit primarily from the information transparency channel to showcase their governance strengths. Meanwhile, technology-intensive firms leverage the green innovation channel more effectively due to their inherent technological advantages.

5.4. Channel Test

To explore the specific channels through which digital finance influences corporate ESG outcomes, the explanatory variables are replaced with the three secondary indicators from the Huazheng ESG rating, denoted as E_Score, S_Score, and G_Score, representing environmental, social responsibility, and corporate governance performance, respectively. Bloomberg ESG rating data is also included for further comparison and validation.

Table 7 presents regression results derived from the Huazheng ESG ratings in M(1) to (3), while M(4) to (6) use Bloomberg ESG ratings. The findings indicate that the effects are more pronounced with the Huazheng ESG ratings as compared to the Bloomberg ESG ratings. In particular, M(4) to M(6) reveal that digital finance exerts a comparatively smaller effect on environmental performance, primarily enhancing a firm's ESG outcomes through improvement in social responsibility and corporate governance. This finding aligns with Y. Mo et al. (2023).

The differences observed in the empirical results between the two ESG rating methods may primarily stem from variation in value orientation, indicator selection, and weight distribution in each methodology (M. Liu, 2022). Local rating agencies, such as Huazheng, tend to emphasize regional policy responses and corporate practices, with a strong orientation toward Chinese-specific institutional and policy contexts (G. Chen et al., 2024). For example, Huazheng includes environmental indicators such as "pollution control investment" and "resource utilization efficiency", which directly reflects the impact of China's environmental regulatory framework. In contrast, international rating agencies, including Bloomberg and MSCI, typically follow a globally standardized ESG framework that prioritizes issues like climate risk and anti-corruption. While these frameworks enhance international comparability, they may overlook local environmental priorities. As a result, short-term improvements in localized environmental performance such as those driven by digital financial policies may be underrepresented in international evaluations but more accurately captured by Huazheng's localized metrics, such as the proportion of renewable energy and pollution control investment (Shen et al., 2023).

Table 7. Channel test.

	M(1)	M(2)	M(3)	M(4)	M(5)	M(6)
	E_Score	S_Score	G_Score	E_Score	S_Score	G_Score
DF	2.310 *** (2.784)	3.387 *** (4.604)	1.892 *** (3.707)	3.249 * (1.841)	2.743 ** (2.421)	2.562 ** (2.478)
_cons	23.426 *** (8.813)	18.729 *** (6.762)	55.257 *** (24.625)	−69.508 *** (−9.428)	−31.546 *** (−6.302)	9.411 * (1.878)
CONTROL	Yes	Yes	Yes	Yes	Yes	Yes
YEAR	Yes	Yes	Yes	Yes	Yes	Yes
INDUSTRY	Yes	Yes	Yes	Yes	Yes	Yes
N	25,800	25,800	25,800	9715	9715	9715
R ²	0.216	0.296	0.262	0.415	0.319	0.688

Notes: M(1), M(2), M(3), M(4), M(5), and M(6) are estimated using fixed-effect models. ***, **, and * denote significance at the 1%, 5%, and 10% level, with t-values in parentheses.

6. Research Conclusions and Policy Recommendations

On 22 October 2023, the inaugural ESG China Forum Innovation Annual Conference was held in Beijing, emphasizing the need to accelerate the implementation of ESG concepts, strengthen ESG, and advance the construction of an ESG framework. In light of the rapid expansion of the digital economy, investigating how China's digital finance sector contributes to improving firms' ESG performance is crucial. This is addressed by this study's empirical analysis.

The primary conclusions are outlined below: The advancement of digital finance greatly enhances corporate ESG performance. Consistently, analysis based on three sub-indices demonstrates that all aspects of digital finance development contribute to promoting ESG performance, whether from the perspective of coverage of breadth, usage of depth, and degree of digitalization. These findings align with the conclusions of [Mu et al. \(2023\)](#); however, it contrasts with the view of [Xue et al. \(2023\)](#), who argue that the coverage breadth of digital finance has no significant impact on corporate ESG performance. A plausible explanation for this discrepancy lies in the functional scope of coverage breadth, which primarily addresses “service accessibility”. When digital financial services are deeply integrated into firm-level operational contexts (reflected in usage depth and the degree of digitalization), their influence on ESG performance becomes more pronounced. Therefore, the impact of the coverage breadth dimension may vary depending on differences in research design, context, and analytical focus.

Second, this study not only empirically validates the mediating role of financing constraints (see, e.g., [Y. Mo et al., 2023](#)) but also extends the analysis by incorporating the roles of digital transformation and internal control quality. Our findings show that digital finance acts as a partial mediator, accelerating digital transformation and relieving a firm's financing limitations, both of which indirectly enhance ESG performance. Moreover, the relationship between digital finance and ESG performance is positively moderated by the strength of the internal control mechanisms. In the context of rapidly advancing digital finance, firms adapt and transform in line with dynamic capability theory, reducing internal and external information asymmetry through digital transformation and enhancing corporate governance. High-quality internal controls facilitate the integration of technological empowerment with governance oversight, ultimately leading to improved ESG performance.

The heterogeneity analysis reveals that the digital finance–ESG relationship varies based on firm characteristics, with stronger impacts observed in small-scale enterprises, non-polluting enterprises, and technology-intensive enterprises. Fourth, channel analysis suggests that digital finance primarily improves ESG outcomes through fostering improvements in a firm's social responsibility and governance, with a relatively weaker effect on environmental responsibility. Of note, our study compares the results of the Huazheng and Bloomberg ESG ratings in the channel analysis, differing from [Y. Mo et al. \(2023\)](#), who relied solely on the Hexun ESG rating. The observed discrepancies in the environmental dimension between these two rating systems highlight the importance of accounting for differences in value orientation, indicator selection, and weight assignment across measurement methods. Hence, research design should not only ensure comparability but also consider the institutional context of the study.

This study offers policy recommendations according to empirical findings. The government should revise policies to align the advancement of digital finance with firm ESG practices. Efforts should concentrate on maximizing the potential of digital finance in supporting enterprises to integrate into digital, green, and technology finance ecosystems, and fostering green innovation and low-carbon transitions. Recognizing the heterogeneous influence of digital finance on ESG performance, policymakers need to adopt differentiated approaches. For instance, small-scale and technology-intensive enterprises could benefit from preferential policies, while heavily polluting enterprises may require a balanced strategy of incentives and constraints to drive ESG improvements. These measures would elevate ESG practices, foster new productivity, and facilitate the transition to sustainability. Ultimately, it is manifested in the high-quality development of both the economy and society.

Second, financial institutions should leverage the inclusive potential of digital finance to facilitate corporate financing, reduce service costs, address information asymmetry, and enhance the efficiency and quality of financial services for the real economy. In line with national policies, institutions should actively implement ESG principles by developing green financial products that address the specific needs of the capital market of China.

Third, enterprises should integrate ESG principles into their management strategies. They should utilize digital finance to support ESG initiatives, increase investments in ESG activities, and strengthen sustainable development capabilities. Businesses should also prioritize digital transformation, improve internal controls, and enhance operational efficiency and risk management while advancing their ESG performance.

This research presents findings regarding the influence of digital finance on corporate ESG performance. However, it has certain limitations. First, the study relies on the DFII-PKU data, which reflects the progress of digital finance in China. Hence, the findings may have limited applicability beyond this regional context, and other countries or regions must consider their specific circumstances when formulating policies. Second, the sample period of 2011–2022 reflects a phase when digital finance in China was still evolving. Therefore, the applicability of these findings to future developments remains uncertain as digital finance continues to progress. Future studies can focus on overcoming these limitations by broadening geographic coverage and extending the sample horizon to provide further evidence to confirm the consistent impact of digital finance on a firm's ESG outcomes.

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Appendix A

Table A1. Description of variables.

Variable Type	Symbol	Variable Definition
Dependent Variable	ESG	Corporate ESG performance, measured by Huazheng ESG rating data
Independent Variable	DF	Digital Inclusive Finance Index, measured by the DFII-PKU and divided by 100
	Cov	The breadth of coverage of the DFII-PKU
	Dep	The depth of use of the DFII-PKU
	Dig	The level of digitalization of the DFII-PKU
Mediating Variable	WW	Financing constraint, measured by the WW index constructed by Whited and Wu (2006)
	CDT	Corporate digital transformation, measured by the frequency of keywords in the firm's annual report, adding 1 before taking the logarithm
Moderating Variable	ICQ	Internal control quality, measured by the DIBO internal control index and divided by 1000
Control Variable		
Firm Characteristics	Age	The firm's listing year plus one, taken as the logarithm
	Size	The firm's total assets, taken as the logarithm
	ROA	The return on the total assets of the firm
	Lev	The ratio of total liabilities to total assets of the company
	Growth	The operating income growth rate of the company
	Tobin's Q	The market value of the company divided by the book value of the total assets
Corporate Governance	SOE	If the company is a state-owned enterprise, the value is 1, otherwise it is 0
	Top1	The largest shareholder's shareholding of the company
	Dual	The value is 1 if the general manager and chairman are the same; otherwise, it is 0.
	Board	The natural logarithm of the number of directors
	Inst	The shareholding ratio of institutional investors
Regional Economic Development	Indep	The percentage of independent directors compared to all directors
	Findev	The ratio of deposits and loans of provincial banking financial institutions to GDP
	GDP	The gross domestic product per city, taken as the logarithm

Table A2. Correlation test results.

	ESG	DF	CDT	WW	ICQ	Age	Size
ESG	1						
DF	0.046 ***	1					
CDT	0.110 ***	0.388 ***	1				
WW	−0.270 ***	−0.078 ***	−0.011 *	1			
ICQ	0.247 ***	−0.090 ***	0	−0.271 ***	1		
Age	−0.088 ***	0.073 ***	−0.044 ***	−0.227 ***	−0.096 ***	1	
Size	0.232 ***	0.179 ***	0.050 ***	−0.841 ***	0.141 ***	0.393 ***	1
Lev	−0.071 ***	0.022 ***	−0.061 ***	−0.304 ***	−0.097 ***	0.358 ***	0.491 ***
ROA	0.201 ***	−0.065 ***	−0.014 **	−0.284 ***	0.381 ***	−0.177 ***	0.026 ***
TobinQ	−0.097 ***	0.015 **	0.092 ***	0.306 ***	−0.053 ***	−0.083 ***	−0.391 ***
Growth	−0.005	−0.012 *	0.023 ***	−0.288 ***	0.149 ***	−0.085 ***	0.035 ***
Board	0.021 ***	−0.145 ***	−0.104 ***	−0.215 ***	0.053 ***	0.137 ***	0.238 ***
Indep	0.090 ***	0.076 ***	0.076 ***	−0.007	0.006	−0.016 **	0.025 ***
Top1	0.102 ***	−0.097 ***	−0.121 ***	−0.251 ***	0.130 ***	−0.038 ***	0.225 ***
Dual	−0.015 **	0.094 ***	0.117 ***	0.133 ***	−0.003	−0.242 ***	−0.173 ***
Big4	0.127 ***	0.046 ***	−0.003	−0.313 ***	0.099 ***	0.062 ***	0.356 ***
SOE	0.066 ***	−0.121 ***	−0.158 ***	−0.258 ***	0.035 ***	0.456 ***	0.351 ***
Inst	0.103 ***	−0.097 ***	−0.110 ***	−0.415 ***	0.137 ***	0.204 ***	0.442 ***
Findev	0.080 ***	0.365 ***	0.191 ***	−0.085 ***	0.018 ***	−0.002	0.134 ***
GDP	0.098 ***	0.479 ***	0.295 ***	−0.062 ***	0.048 ***	−0.048 ***	0.093 ***
	Lev	ROA	TobinQ	Growth	Board	Indep	Top1
Lev	1						
ROA	−0.359 ***	1					
TobinQ	−0.292 ***	0.186 ***	1				
Growth	0.019 ***	0.279 ***	0.061 ***	1			
Board	0.127 ***	0.021 ***	−0.128 ***	−0.020 ***	1		
Indep	−0.002	−0.017 ***	0.037 ***	−0.004	−0.537 ***	1	
Top1	0.063 ***	0.130 ***	−0.121 ***	−0.003	0.036 ***	0.046 ***	1
Dual	−0.128 ***	0.028 ***	0.086 ***	0.037 ***	−0.186 ***	0.106 ***	−0.077 ***
Big4	0.103 ***	0.038 ***	−0.088 ***	−0.012 *	0.077 ***	0.048 ***	0.153 ***
SOE	0.279 ***	−0.086 ***	−0.174 ***	−0.076 ***	0.276 ***	−0.047 ***	0.246 ***
Inst	0.190 ***	0.144 ***	−0.055 ***	0.042 ***	0.228 ***	−0.048 ***	0.529 ***
Findev	−0.009	−0.033 ***	0.022 ***	−0.012 **	−0.039 ***	0.047 ***	0.035 ***
GDP	0.005	−0.017 ***	0.024 ***	0.002	−0.077 ***	0.062 ***	0.017 ***
	Dual	Big4	SOE	Inst	Findev	GDP	
Dual	1						
Big4	−0.058 ***	1					
SOE	−0.313 ***	0.131 ***	1				
Inst	−0.205 ***	0.241 ***	0.424 ***	1			
Findev	0.029 ***	0.136 ***	0.014 **	0.012 *	1		
GDP	0.079 ***	0.137 ***	−0.027 ***	−0.016 **	0.589 ***	1	

Notes: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table A3. Summary of industry heterogeneity on corporate ESG performance.

Regression Results	Industry Code	Polluting Enterprises Involved	Technology-Intensive Enterprises Involved
Significantly Positive	A02–A05, B09–B11, C13–C15, C17–C43, D44–D46, E48–E50, F51, F52, G54, G56, G59, H61, H62, I63–I65, K70, L72, M73, M74, N77, N78, O80, O81, P82, R85, R86, R88, S90	B09, C17, C19, C22, C25–C26, C28–C32, D44	C27, C29, C33, C35–C41, I65, M74, N77
Significantly Negative	B10	-	-
Not Significant	B06, B07, B08, E47, G53, G55, G58, G60, L71, M75, O79, Q83, R87	B06–B08	-

Notes: The industry code of the benchmark group is A01 (agriculture industry) while using industry dummy variables for analysis.

Table A4. Explanation of industry code (polluting and technology-intensive enterprises).

	Industry Code	Industry Name
Polluting Enterprises	B06	Coal mining and washing industry
	B07	Oil and gas mining industry
	B08	Ferrous metal mining and dressing industry
	B09	Non-ferrous metal mining and dressing industry
	C17	Textile industry
	C19	Leather, fur, feather and its products and footwear industry
	C22	Paper and paper products industry
	C25	Petroleum processing, coking and nuclear fuel processing industry
	C26	Chemical raw materials and chemical products manufacturing industry
	C28	Chemical fiber manufacturing industry
	C29	Rubber and plastic products industry
	C30	Non-metallic mineral products industry
	C31	Ferrous metal smelting and rolling processing industry
	C32	Non-ferrous metal smelting and rolling processing industry
	D44	Electricity, heat production and supply industry
Technology-intensive Enterprises	C27	Pharmaceutical manufacturing
	C29	Rubber and plastic products manufacturing
	C33	Metal products manufacturing
	C35	Special equipment manufacturing
	C36	Automobile manufacturing
	C37	Railway, shipbuilding, aerospace and other transportation equipment manufacturing
	C38	Electrical machinery and equipment manufacturing
	C39	Computer, communication and other electronic equipment manufacturing
	C40	Instrument manufacturing
	C41	Other manufacturing
	I 65	Software and information technology services
	M74	Professional technical services
	N77	Ecological protection and environmental management

Notes: The industry classification of listed companies follows the guidelines established by the China Securities Regulatory Commission (CSRC).

Notes

- ¹ Retrieved from the official website of the State Council of China: https://www.gov.cn/zhengce/zhengceku/202404/content_6944878.htm (accessed on 11 October 2024).
- ² Retrieved from <https://www.china-briefing.com/news/chinas-stock-exchanges-announce-esg-reporting-guidelines-for-listed-companies/> (accessed on 11 October 2024).
- ³ “AAA” rating is assigned a value of 9, “AA” is assigned 8, and subsequent ratings—“A”, “BBB”, “BB”, “B”, “CCC”, “CC”, and “C”—are assigned values of 7, 6, 5, 4, 3, 2, and 1, respectively.
- ⁴ The classification is based on the Guidelines for Industry Classification of Listed Companies by the China Securities Regulatory Commission in 2012.
- ⁵ Polluting companies are identified using specific industry codes (B06–B09, C17, C19, C22, C25–C26, C28–C32, and D44, covering 15 industries).
- ⁶ The classification is based on the same policy document as Section 5.3.2. The industry codes for technology-intensive enterprises are C27, C29, C33, C35–C41, I65, M74, and N77.

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