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The Impact of Firm Digital Transformation on ESG Performance: Evidence from China

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ABSTRACT

Growing consciousness about sustainability and the onset of the digital era have affected the corporate ESG (Environmental, Social, and Governance) outcomes to the forefront of new debates. A-share quoted firms in Shanghai and Shenzhen between 2006 and 2022 are examined in this research for the sake of exploring how digitalization in businesses affects ESG ratings. Findings suggest a positive correlation between digital initiatives and ESG metrics improvements. These findings are consistent even after multiple robustness checks.Additionally, the study delves into the mechanisms driving this primary relationship, discovering that digital advances in firms enhance ESG scores by easing financial limitations, diminishing information disparities, and bolstering technological innovation. The research further reveals variable impacts based on firm size and geographical location.

Keywords: *ESG Performance, Financial Constraint, Information Asymmetry*

I. INTRODUCTION

The ESG conception has become a critical aspect of international business dialogue. Seen as a pivotal gauge of an enterprise's commitment to sustainability, ESG performance is increasingly tied to long-term prosperity. The term 'ESG investment' was initially introduced by the United Nations Environment Program (UNEP) in 2004, calling for the infirm of environmental, social, and governance problems related to investment decisions. That same year, the UNEP Finance Initiative emphasized the active effects of ESG factors on sustainable equity pricing in its report. Since the formal introduction of ESG, the consensus has grown globally, with investors recognizing the necessity for firms to develop comprehensive ESG evaluation frameworks that address ecological, social, and governance aspects in conformity to sustainable development objects[1].

The digital economy heralds a transformative era. As digital technologies evolve, the rapid combination of artificial intelligence (AI), blockchain, cloud computing; additionally, big data is reshaping corporate objectives and governance. This evolution intensifies the competitive landscape for businesses. The related researchers define digital transformation (DT) as the adoption of digital techniques by firms within the digital landscape to modify their business models and operations, ultimately boosting production capabilities and market competitiveness[2]. This process entails a comprehensive overhaul of a firm's internal control environment and is a strategic initiative[3]. A key focus of digital transformation is leveraging digital tools to redefine value propositions for customers, as well as to enhance interactions and collaborations with them.

Digital transformation represents a novel asset for firms and plays a pivotal role under the background of sustainable development and the economic framework[4]. The potential of digital transformation to foster sustainable growth is substantial[5]. Nations are leveraging cutting-edge technologies and data analytics to enhance resource efficiency, cut carbon emissions, and boost departmental operational effectiveness. Nonetheless, there are concerns that digital transformation might adversely affect ESG performance[6]. The production, operation, and disposal of technology-related hardware contribute to nearly 2% of the world's greenhouse gas emissions[7]. The academic field has extensively examined the associations between digital transformation and ESG performance. Research on digital transformation has traditionally concentrated on its effects on economic growth, corporate governance, performance, and innovation efficiency[8]. Studies pertaining to ESG performance have often focused on its influence on corporate outcomes,

innovation, and risk management[9]. Speaking of the influences of DT upon the corporate ESG performance, existing literature typically addresses the three separate sub-dimensions of DT's influence upon ESG. However, the relevant comprehensive researches is very scarce, with findings that are not always aligned. Additionally, there exists a noted shortage of researches which examine the specific pathways through which technological innovation and financial constraints are affected.

Investigating the correlation between DT and ESG performance, as well as their collective influence on a firm's total factor productivity, is essential for fostering firms' high-quality growth and overall sustainable economic and social progress. The findings indicate that DT positively impacts a corporate ESG performance, with these outcomes demonstrating resilience across various tests. Through mechanism analysis, the study reveals that digital transformation aids in mitigating financial restrictions, enhancing internal control quality, reducing information asymmetry, and boosting innovation performance. It also detects diverse effects based on firm size and location. In terms of scholarly contribution, this research addresses gaps in previous studies by presenting a novel perspective on the positive influences of DT upon the ESG performance, specifically through financial constraints, information asymmetry, and technological innovation. Utilizing A-share quoted companies in Shanghai and Shenzhen between 2006 and 2022 as the sample, this paper employs Python for web scraping to gauge firms' digital transformation levels and uses Stata for statistical analysis to quantitatively assess its impact on ESG performance and the mechanisms involved. Moreover, the study delves into the primary effect's underlying mechanisms and identifies the heterogeneous effects based on firm size and geographic region to deepen the research and enhance its persuasiveness.

The structure of this paper is as below: Section 2 discusses the review of existing literature and the formulation of hypotheses. Section 3 depicts the research design and approach employed. Section 4 elaborates on the outcomes of the model and the statistical techniques applied. Section 5 delves into additional analyses, including the examination of heterogeneity. Section 6 outlines the conclusions and the implications for policy.

II. LITERATURE REVIEW & HYPOTHESIS DEVELOPMENT

2.1 Firm Digital Transformation And ESG Performance

In the past, the development of firms often relied on the theories of maximizing profits and maximizing shareholder value as action guidelines, with a single goal as the direction of firms management [10]. However, according to stakeholder theory, firms need to consider the shareholders` interests. Additionally, they should balance and pay attention to the disparate demands of multiple stakeholders, taking into account aspects such as employees, customers, suppliers, society, and the environment in business decision-making [11]. In addition, with the gradual improvement of the modern firms system, the demand for the working class to safeguard their authorities and interests continues to rise. Moreover, in recent years, governments of countries have successively implemented a series of laws and regulations to curb corporate misconduct, thus raising new demands for corporations to achieve community responsibility. The conception of corporate social responsibility (CSR) has been the inevitability in history.

Nowadays, on account of frequent global extreme weather, continuous trade frictions, and severe environmental protection situations, the ESG concept is increasingly receiving attention from various stakeholders of firm, prompting managers to no longer blindly pursue economic returns and shareholder priority profit distribution methods. Instead, they use a long-term vision to seek a model that is more in line with the conception of sustainable development, abandoning the original "profit first" thinking, Forcing firms to undergo transformation and upgrading[9]. However, it must be pointed out that implementing ESG activities usually requires financial investment, including expenses for equipment updates, process improvements, and other aspects[12]. Especially in environmental activities such as reducing carbon emissions and using renewable energy, significant investments may be required and it may take some time to achieve positive returns[13]. On the other hand, the benefits brought by ESG activities are often difficult to quantify directly, and this uncertainty makes it difficult for firms to make a clear economic evaluation of the costs and benefits of carrying out ESG activities[14], leading to some firms hesitating.

Related studies have shown that after digital transformation, the support of digital technology can help firms more efficiently enhance their green image, customer reputation, and product quality, thereby bringing profit growth to the

firm[15]. At the same time, DT can also triggers the shifts in organization structure, internal management, and other governance respects to firms, reduce the expected costs of ESG activities, and even change their own profit models[16]. While reducing firm costs, it can create more employment opportunities for society, thereby promoting sustainable economic growth. The hypotheses proposed in this paper include the following:

H1: The process of digital transformation positively influences the ESG performance of firm.

2.2 Mechanism Analysis

In this section, this paper explores how various factors can affect the relationship between a corporate DT and its ESG performance, focusing on three primary elements independently.

2.2.1 Financial Constraint

The initial focus of this paper is on examining how corporate financial limitations impact ESG performance. Digital transformation is recognized for mitigating information asymmetry between firms and markets, thus easing corporate finance constraints. Previous studies have indicated that the digital economy lessens the negotiation and opportunity costs associated with corporate debt financing, subsequently lowering firms' financing expenses[17]. Additionally, it has been shown that digital transformation significantly lightens the financial load on firms[18]. Furthermore, the hastening of digitalization aids in establishing and refining the financial credit system. This enhancement can effectively mitigate moral hazards and adverse selection in financial lending, consequently diminishing firms' financial constraints[19]. A reduction in financing restrictions may motivate firms to pursue green initiatives, decrease pollution emissions, make charitable contributions, and improve internal management. These actions contribute to more excellent environmental performance, stronger social responsibility, and more efficient governance, thereby boosting firms' ESG performance[20]. Based upon these observations, the hypotheses are put forward:

H2: Digital transformation can improve the ESG performance of firms by alleviating their financial constraints.

2.2.2 Information Asymmetry

Viewing from a different angle, information asymmetry significantly impacts the enduring growth and sustainability of firms. Typically, the availability of funding is hampered by information asymmetry, leading fund suppliers to seek higher returns to mitigate their risks, which in turn increases the profitability pressures on firms[21]. The digital transformation within firms is a pivotal player in diminishing the level of information asymmetry, thereby relieving financial stress and consequently enhancing their ESG performance[22]. Digital transformation aids firms in bolstering their internal control mechanisms and improving the quality of information exposure, which reduces information asymmetry[23].

The prominent advantage of digital transformation lies in the utilization of digital technique of quickly and accurately obtaining the big data generated in firm production and operation, and with powerful intelligent analysis capabilities to parse and encode it into usable information, improving information utilization[24].On the other hand, digitalization also helps to eliminate the boundaries between various departments within the firm, break the dilemma of "information silos"1[25] , accelerate the speed of information dissemination and circulation, enable shareholders to timely obtain information related to firm production and operation, implement effective supervision over management, and improve information transparency. Meanwhile, as more and more countries, especially large economies, attach great importance to the digital economy progress, firms implementing DT are also more likely to obtain positive expectations in the market[26], thereby attracting more analyst attention and media coverage, enhancing external supervision, and

[1] Information silo refers to an isolated management system incapable of communicating or sharing information with other, related systems.

improving the information environment. Based upon this, the hypothesis is put forward in this article:

H3: Digital transformation can improve the ESG performance of firms by effectively reducing the degree of information asymmetry.

2.2.3 Technological Innovation

In addition, many industry practices and empirical studies have revealed a stable positive transmission mechanism between digital transformation, technological innovation capabilities, and ESG performance.

Digital transformation is capable of promoting the improvement of technological innovation level in these three aspects. At first, increase investment in research and development. By implementing digital transformation, firms can enhance their research and development capabilities[27]. Digital transformation significantly enhances their technological innovation capabilities, investment, and quality, thereby improving the overall level of technological innovation in firms[28]. Secondly, improve operational efficiency. Digital transformation can promote technological innovation in firms by optimizing the allocation of innovative elements, reducing firm costs, and other means[29]. By leveraging digital strategies and technological means, firms can accelerate the operation speed of manufacturing processes, promote process improvement, and strengthen the compressive strength of supply chains and industrial structures[30]. They can optimize information acquisition and product development through new technologies and platforms, and enhance their innovation capabilities[31]. Thirdly, improve the level of human capital. Digital transformation enhances employees' ability to access valuable external knowledge and information resources, providing them with opportunities for self-learning and growth. It helps employees improve their personal human capital level, thereby promoting technological innovation in the firm[32].

The technological innovation becomes a key player in influencing the ESG performance of firms undergoing DT through several mechanisms. To begin with, technological innovation enables firms to lower energy usage and decrease emissions of pollutants during their production processes, which in turn bolsters their environmental stewardship and performance[33]. Next, it contributes to the enhancement of product quality, safety, and dependability, which amplifies the firms' accountability to their customers, workforce, and the broader community[34]. Lastly, technological innovation is instrumental in advancing the quality of information exposure and transparency of corporations, which helps to refine their internal governance structures[35].

Based upon this, the hypothesis is put forward in this article:

H4: Digital transformation can improve the ESG performance of firms by improving their technological innovation level.

Through the research framework as depicted in Figure 1, all hypotheses are summarized. Firstly, we tested the direct effect of DT upon corporate ESG performance. Secondly, we attempt to investigate the relationship between underlying mechanisms and firm digital transformation. Then, we apply empirical analysis to explore the quantitative relationships.

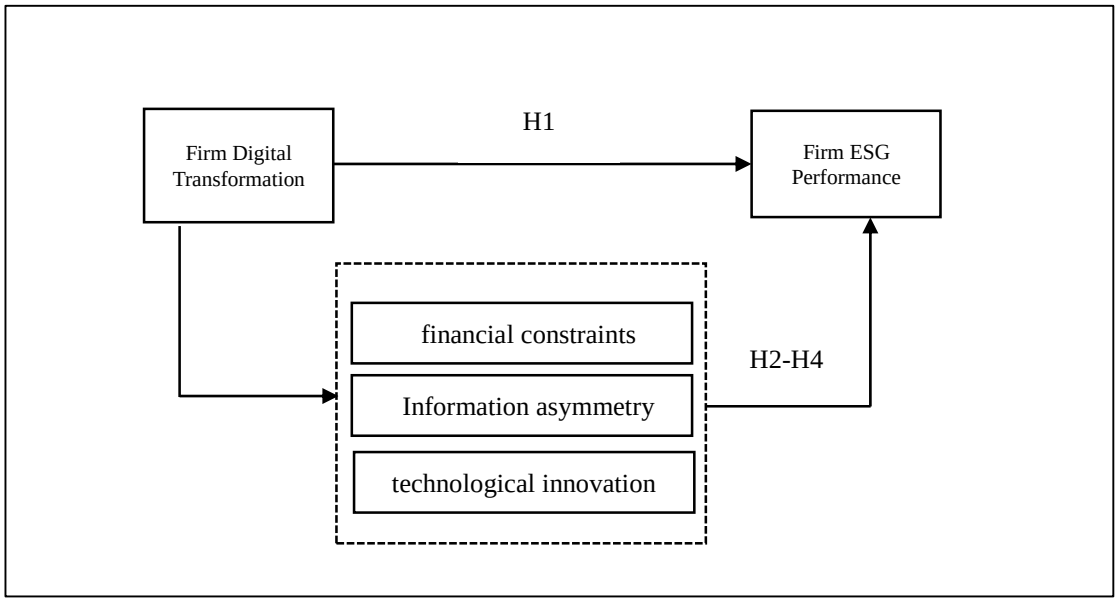

Figure 1 Research framework

III. RESEARCH DESIGN

3.1 Data and Sample

This study employs the information from all A-share quoted companies on the Shanghai and Shenzhen Stock Exchanges between 2006 and 2022. It utilizes Python web scraping technology to measure the DT degree within these companies and investigate its influence on their ESG performance[36].To ensure an accurate assessment of DT impact upon companies, this study excludes certain types of firms: those in the financial sector, firms designated with *ST or ST (indicating particular financial conditions), and firms with accounting or financial reporting issues.

The methodology for quantifying the frequency of digital transformation within firms is based on the research by Wu Fei and Zhao Chenyu[37]. The control variables are primarily derived from the superior firms' annual reports. The final sample comprises an unbalanced panel consisting of 27,119 firm-year observations spanning from 2006 to 2022.

3.2 Variables

3.2.1 Independent Variable: Firms Digital Transformation

The methodology outlined in the paper for assessing the corporate digital transformation involves the utilization of a Python web scraper to compile annual reports from all A-share quoted companies on the Shanghai and Shenzhen Stock Exchanges. The text content from these reports is derived by means of Java PDF Box library, which works as the data repository for follow-up keyword filtering. In identifying the keywords indicative of a corporate DT, the paper conducts focused discussions within both academic and industrial spheres. The text from the firms' annual reports is then processed using Python to create a data pool. The frequency of the identified feature words, as depicted in Figure 1, is searched, matched, and tallied. This frequency data, particularly for key technological areas, is collected and aggregated to formulate the final total word frequency metric, which is used to construct an index system to gauge firm digital transformation. Providing the "right-skewed" essence of the data, this article applies a logarithmic transformation (logarithm plus one) to develop a comprehensive indicator that represents the digital transformation of firms.

3.2.2 Dependent Variable: ESG Performance

To assess the ESG performance of firms, the paper utilizes the Huazheng ESG rating system, which categorizes the

ESG performance of quoted companies into nine ascending tiers: C, CC, CCC, B, BB, BBB, A, AA, and AAA. Each level is designated a corresponding value between 1 and 9, with higher values denoting superior ESG performance. The Huazheng ESG ratings are particularly relevant for the domestic market as they incorporate a range of indicators that are pertinent to the current developmental stage, such as information disclosure quality, penalties issued by the CSRC, and efforts in targeted poverty alleviation[38].

Additionally, the paper conducts robustness checks by substituting dependent variables. It replaces the Huazheng ESG index with the Bloomberg ESG index and tests across different heterogeneity groups.

3.2.3 Control variables

For the purpose of mitigating the possible endogeneity issues which might arise from omitted variables, the paper incorporates an array of control variables, which are as follows:

(1) Firm Scale (Size): This is represented by the total assets of a company and expressed as the natural logarithm of this figure. (2) Age of the Firm (FirmAge): Computed as the natural logarithm of the difference between the current year and the year when the company was established. (3) Firm Leverage (Lev): Defined as the percentage of gross liabilities to total assets of a company. (4) Return On Assets (ROA): It is the net profit margin based on the total assets of a company. (5) Cash Holdings (Cash): Represented by the percentage of net cash flow from operational activities to the total assets of a company. (6) Percentage of Independent Directors (Indep): This reflects the percentage of isolated directors to the total quantity of the board. (7) Dual Role (Dual): Indicates if the general manager and chairman are the identical individual or if one individual holds both roles. (8) Board Size (Board): Shown as the natural logarithm of the total quantity of the board. (9) Ownership of the Largest Shareholder (Top1): This indicates the proportion of shares possessed by the corporate largest shareholder.

These control variables are selected to account for various aspects of a firm's characteristics that could influence its ESG performance, thereby providing a more robust analysis. For detailed information about any variable, it can be found in the variable definitions (Table 1).

Table 1. Definitions of variables

Variable names	Notations	Definitions
Firm ESG Performance	*ESG*	Utilizing Huazheng Index ESG rating as a proxy variable representing corporate ESG practices. The index assigns a score varying between 1 and 9, with higher scores illuminating stronger ESG performance. By averaging the four quarterly ratings each year, this paper captures the annual ESG performance of the firm.
Firm Digital Transformation	*FDT*	Summarize the frequency of all words from four dimensions: AI, Cloud Computing, Blockchain, and Big Data, and take the logarithm plus 1 for calculation.
Firms Size	*Size*	The natural logarithm of total assets
Return On Assets	*ROA*	Return on total assets of companies
Firm Age	*FirmAge*	The natural logarithm of a corporate listing time
Size Leverage	*Lev*	Total corporate liabilities split by total assets
Cash Holdings	*Cash*	The percentage of year-end monetary funds to mean total assets
The ownership of the largest shareholder	*Top1*	The proportion of shares owned by the largest shareholder to the total quantity of shares
Board Size	*Board*	Total number of directors
Percentage of Independent Directors	*Indep*	The percentage of independent directors to the total quantity of the board
Dual Role	*Dual*	If the chairman and general manager are the identical person, assign a value of 1; or, assign a value of 0

3.3 Empirical Model

This fixed effect model is created based upon the aforementioned theoretical analysis, with the aim of researching the correlation between Firms DT and ESG performance:

$$ESG_{it}=\beta_0+\beta_1 FDT_{it}+\beta_2 Controls_{it}+\sum Year+\sum Firm+\varepsilon_{it} \quad (1)$$

The subscript variables *i* and *t* refer to firm *i* in year *t*. ESG_{it} refers to the ESG performance firm i in year t. The independent variable FDT_{it} serves as the proxy for DT, as elaborated in preceding description. $Controls_{it}$ encompasses the control variables at the level of the company, including Firm Scale, Firm Return On Assets, Firm Age, Size Leverage, Cash Holdings, Ownership of the biggest shareholder, Board Size, Percentage of Independent Directors, and Dual Role, employed to mitigate the influence of factors that could impact total factor productivity at the micro level of the firm. Additionally, this study incorporates fixed effects for firms $\sum Firm$ and year $\sum Year$, along with the random error term ε_{it}.

IV. RESULTS

4.1 Descriptive Statistics

In order for the precision of the data, the data is processed as follows: (1) Excluding special processing firms (ST, * ST). (2) Exclude firms with severe data gaps. (3) Excluding the more specialized financial and insurance industries. (4) For the purpose of eliminating the impact of outliers upon estimation results, the total continuous variables were subjected to 1% and 99% quantile truncation. Table 2 displays the descriptive statistics of the major variables. The mean ESG score for firms reaches approximately 4.21, with a standard deviation of around 0.983, suggesting that the ESG performance of most companies is notably commendable. The mean level of firm digital transformation (FDT) stands at about 12.56, with a standard deviation of roughly 33.05, indicating varying levels of digital transformation among Chinese listed firms. The descriptive statistics of control variables corresponds closely to former researches in the field.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std.dev.	Min	Median	Max
ESG	27,119	4.2111	0.9833	1	5	9
FDT	27,119	12.5616	33.0563	0	2	589
Size	27,119	0.4401	1.2315	-0.1947	22.1462	178.3455
ROA	27,119	0.04175	0.0726	-2.8341	0.03999	0.6444
FirmAge	27,119	9.9539	7.7074	0	9	32
Lev	27,119	0.4259	0.2006	0.0075	0.4117	0.9976
Cash	27,119	0.1628	0.1256	0.0598	0.4279	0.9283
Top1	27,119	35.1958	15.0055	1.8400	32.6300	89.9999
Board	27,119	8.6286	1.7224	3	9	18
Indep	27,119	37.4659	5.5238	0	36.3600	80
Dual	27,119	0.2726	0.4453	0	0	1

4.2 Baseline Result

Table 3 presents the Impact of Firm Digital Transformation on ESG Performance. The univariate regression outcomes are displayed the first column, controlling solely for corporate fixed effects as well as year fixed effects. Subsequently, column (2) introduces control variables at the firm level to address potential omitted variable bias. It is discovered that the regression coefficient for firm ESG performance on total factor productivity is significant statistically at the level of 1%. Economically speaking, a 1% increase in digital transformation corresponds to a 0.037-unit rise in ESG performance. This suggests that enhancing the extent of DT is capable of positively impacting the corporate ESG

performance, supporting the core conclusion. It can be inferred that ESG advantages effectively enhance firms' total factor productivity, thereby validating hypothesis H1.

Table 3. The Impact of Firm Digital Transformation on ESG Performance

	（1）	（2）
	ESG	*ESG*
FDT	0.051***	0.037***
	(4.642)	(4.064)
Size		0.244***
		(19.339)
ROA		1.322***
		(7.132)
FirmAge		-0.138***
		(-9.949)
Lev		-0.563***
		(-7.295)
Cash		0.464***
		(5.401)
Top1		-0.000
		（-0.002）
Board		0.007
		（0.800）
Indep		0.014***
		（6.424）
Dual		-0.067***
		（-2.809）
Constant		3.267***
		（12.316）
N	27119	27119
Adj.R^2	0.6538	0.6837
Year FE	YES	YES
Firm FE	YES	YES

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

4.3 Robustness Test

In order for the robustness of our discoveries, a series of robustness tests were implemented. Firstly, we replaced the independent variable by introducing dummy variables based on available data. Specifically, we created the DFDT dummy variable to identify firms implementing digital transformation. The value of this is 1 for companies with non-zero FDT values. The regression outcomes are shown in Table 4, the first column.

Secondly, we replaced the dependent variable by substituting the ESG performance data from Huazheng Firms with ESG data sourced from Bloomberg Consulting in the robustness tests for regression. The Bloomberg corporate ESG data, rated on a scale of 0-100, encompasses three aspects: environmental (Env), social responsibility (Soc), along with corporate governance (Gov)[39]. The regression outcomes are expressed in Table 4, columns (2) to (5). Despite the replacement of the dependent variable and regression across different dimensions, the direction and statistical significance of FDT remained consistent with the initial results.

Following these replacements, the results indicate that FDT continues to positively impact firm ESG performance. Through these adjustments, our core conclusion remains robust and reliable, affirming that digital transformation significantly enhances firms' ESG performance.

Table 4. Robustness tests

Variables	（1） *ESG*	(2) *ESG_PB*	(3) *Env*	(4) *Soc*	(5) *Gov*
FDT		0.0381***	0.0245***	0.0185*	0.0237
		(2.3696)	(2.1505)	(1.8562)	(1.9960)
DFDT	0.0267***				
	(2.1958)				
Controls	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Adj.R^2	0.7002	0.7008	0.6961	0.7101	0.5805
Obs	27119	8788	7425	8421	8646

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

4.4 Mechanism Discussions

For the purpose of coping with the financial constraint effect of firm digital transformation, this research uses the CSMAR China Listed Firm Management Dilemma Research Database to obtain the KZ financial constraint index [2] of A-share superior firms, and uses its logarithmic processed data (*FC-KZ*) for testing. The specific inspection outcomes are displayed in Table 5. Additionally, it is indicated that the DT role in enlarging corporate financing and eliminating corporate financial constraints to improve ESG performance[40], is supported by H2 in this paper. Therefore, we find that financial constraint is one of the underlying mechanisms of the main effect. The research hypothesis H2 in this paper is valid.

Table 5. Mechanism analysis: Channel testing of financial constraint effects in firms digital transformation

Variables	（1） FC-KZ
FDT	-0.0013***
	(0.01)
Control variables	YES
Firm FE	YES
Time FE	YES
Adj.R^2	0.7954
Obs	7024

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

For the purpose of dealing with the impact of firm digital transformation on information transparency, this study utilized the comprehensive index of internal control information from DiBo Data Consulting. The analysis was conducted on the logarithmically transformed data (*IC*), and the outcomes are shown in Table 6. The discoveries in Table 6 indicate that the corporate digital transformation significantly enhances the disclosure of internal control information[41]. This signifies that firm digital transformation contributes to increased transparency of internal information, mitigates information asymmetry, encourages firms to genuinely and effectively uphold their social responsibilities, consequently enhancing firms' ESG performance[42]. As a result, the research hypothesis H3 posited in this study is supported.

[2] KZ（Kauffman Zingales） Index is an indicator proposed by American economists Joshua Lerner and Luigi Zingales to measure the degree of competition in financial markets. It reflects the difficulty that companies face in obtaining external capital in different financial markets.

Table 6. Mechanism analysis: Channel testing of information asymmetry effects in firms digital transformation

Variables	（2） IC
FDT	0.0038***
	(2.2651)
Control variables	YES
Firm FE	YES
Time FE	YES
Adj,R^2	0.7633
Obs	12080

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

In examining the influence of firm DT upon technological innovation, this study leveraged insights from prior literature and accessed pertinent patent classification number of A-share quoted companies from CNRDS (China Research Data Service Platform). This data was cross-referenced with the patent classification numbers in the Green Patent List issued by the World Intellectual Property Organization (WIPO) to determine the count of applications for green invention patents as well as green utility model patents among listed firms. The logarithmically transformed data (ENV) was used for analysis, as detailed in Table 7. In Table 7, it is indicated that a remarkable enhancement in green technology creation results from the corporate DT. This underscores that the corporate DT fosters green technology innovation, encouraging firms to shoulder greater environmental responsibilities and thereby paving the way for improved ESG performance[43]. Consequently, the research hypothesis H4 posited in this study is upheld.

Table 7. Mechanism analysis: Channel testing of technological innovation effects in firms digital transformation

Variables	（3） ENV
FDT	0.0235***
	(3.6651)
Control variables	YES
Firm FE	YES
Time FE	YES
Adj.R^2	0.8115
Obs	10289

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

V. FURTHER ANALYSIS

5.1 Heterogeneity Analysis-Based On Firm Size

The company size plays an irreplaceable part in impacting its capability of effectively enhancing ESG performance[44]. This study utilizes total assets as a metric to gauge firm size, as per available data. Firms are categorized based on total assets, with the lowest 30% classified as small firms, those between 30% and 70% as medium-sized firms, and the top 30% as big companies. Subsequently, the model (1) estimates were recalibrated based on firm size categories. The regression outcomes in Table 8 reveal that the influence of DT upon ESG performance differs across firm sizes. Specifically, the DT coefficients reach 0.0135 for small companies, 0.0336 for medium-sized companies, and 0.0502 for large companies. The significance levels vary, with digital transformation being significant at the 10% level for small firms, 5% level for medium-sized firms, and 1% level for large firms. This suggests that as firm size increases, the impact of DT upon ESG performance becomes more pronounced.

Based upon the above data and existing literature case analysis, this paper speculates that large firms have significant advantages in funding, technology, personnel, and other aspects, which can provide sufficient support for innovation activities[45]. Compared to large firms, although small and medium-sized firms have a stronger willingness to innovate,

their R&D investment is generally lower due to the above factors[46]. Firms can alleviate financial constraints through digital transformation and help establish a good social responsibility image[47]. By improving information control capabilities, information is capable of being improved and processed in time and effectively, lessening the degree of information asymmetry[48]. And by improving employee benefits, attracting more innovative talents to join, enhancing the degree of technical innovation[49]. Ultimately, the progression of ESG performance is achieved.

Table 8. Heterogeneity Analysis Based on firm Size

Variables	Firm Size		
	Small	Medium	Large
	ESG	ESG	ESG
FDT	0.0135*	0.0336**	0.0502***
	(0.0978)	(0.1894)	(0.3187)
Controls	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
N	8038	11990	8019
Adj.R^2	0.7074	0.6628	0.6315

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

5.2 Heterogeneity Analysis-Based on Region

Table 9 presents an analysis based upon the distinct features of disparate regions in China, namely the eastern, central, and western regions. The influence of corporate DT upon enhancing ESG performance might change across regions due to variations in regional economic progress and institutional environments. The analysis reveals that the ESG regression coefficient for firms in eastern region is obviously positive at the level of 1%, significant at the 10% level in the central region, and not prominent in western region. The study posits that the corporate DT in western region does not significantly impact ESG performance. This can be ascribed to some elements. First of all, the western region faces relative inadequacies in infrastructure and resource support compared to the eastern and central regions, constraining the pace and quality of DT and subsequently affecting ESG performance. The eastern and central regions, being more economically developed with better infrastructure and resource support, facilitate firms in undertaking digital transformation and enhancing ESG performance. Secondly, the western region experiences a scarcity of high-quality talent, particularly in the digital domain, hindering firms from effectively driving digital transformation and resulting in insignificant ESG performance. In contrast, the eastern and central regions boast more abundant talent reserves, with a greater presence of high-quality professionals engaging in digital transformation efforts, thereby bolstering ESG performance. Furthermore, the western region's relatively underdeveloped nature, coupled with limited market demand and a lack of incentive for firms to pursue digital transformation, impacts ESG performance. Conversely, the eastern and central regions exhibit robust market demand, compelling firms to intensify their digital transformation efforts to enhance ESG performance.

In conclusion, central and eastern areas hold advantages over the western area in terms of infrastructure, talent availability, and market demand, fostering a conducive environment for firms to engage in digital transformation and thereby elevate their ESG performance.

Table 9. Heterogeneity Analysis Based on regions

Variables	Regions		
	Eastern	Central	Western
	ESG	ESG	ESG
FDT	0.0608***	0.0194*	0.0093
	(0.4173)	(0.1055)	(0.0712)
Controls	YES	YES	YES

Firm FE	YES	YES	YES
Year FE	YES	YES	YES
N	16497	5017	5478
Adj.R^2	0.6972	0.5254	0.4115

Notes. T-statistics in parentheses. * p<0.1,** p<0.05,*** p<0.01.

VI. CONCLUSION

The study on the ESG performance of firm digital transformation is grounded in the growing emphasis on CSR and sustainable development. This research aims at offering both theoretical insights and practical guidance for firms seeking to enhance their sustainable development practices and social responsibility initiatives. The study's background encompasses various dimensions, including societal, environmental, economic, and regulatory aspects. Through empirical analysis, the study draws the following conclusions: Firstly, the corporate DT significantly enhances the ESG performance. Secondly, DT positively impacts ESG performance by addressing financial constraints, reducing information asymmetry, and fostering firm innovation. By enhancing transparency and efficiency, digital transformation can lower financing costs, thereby enhancing ESG performance.

Based upon the aforementioned conclusions, this paper puts forward these recommendations: Firstly, firms should explore diverse financing channels, such as bank loans, equity financing, and bond issuance, to secure adequate funds for digital transformation. Developing effective fund utilization strategies can optimize investment returns. Secondly, fostering long-term correlations with stakeholders, like investors, suppliers, customers, employees, and communities, can facilitate the co-creation of ESG goals and action plans. Lastly, firms are encouraged to cultivate an innovation culture, empowering employees to propose innovative ideas, collaborating with research institutions and innovative firms, and driving continuous technological and business innovation. The digital transformation of firms can spur innovation, green technology adoption, and sustainable development, yielding positive impacts upon ESG performance.

However, despite the research's valuable insights, there are certain limitations that warrant acknowledgment. Firstly, the research sample predominantly focuses on quoted companies in China, implying that the influence of DT upon ESG performance may vary across countries and regions. Secondly, while the study delves into potential mechanisms and heterogeneity, it does not delve deeper into exploring these variables. The paper encourages future research endeavors to further investigate these mechanisms for a more comprehensive understanding.

Data sharing agreement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonab le request.

Declaration of Conflicting Interests

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