Research Article

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The Impact of Firm Digital Transformation on Environmental, Social, and Governance Performance: Evidence from China

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Abstract: Growing consciousness about sustainability and the onset of the digital era have affected the corporate environmental, social, and governance (ESG) outcomes to the forefront of new debates. This article attempts to use statistical analysis software such as Stata to explore relevant issues. A-share listed 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, this article 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. This article further reveals variable impacts based on firm size and geographical location.

Keywords: ESG performance, financial constraint, information asymmetry

1 Introduction

Accompanied by the flourishing development of the enterprise economy, Soares (2022) found that the environmental, social, and governance (ESG) conception has become a critical aspect of international business dialog. According to the research by Lu et al. (2024), to be 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 ESG 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. Zhong et al. (2023) also found that, 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 ESG aspects in conformity to sustainable development objects. Many studies have shown that digital transformation (DT) has a significant impact on the sustainable development of firms. It can not only provide reliable technical support for sustainable development, but also help firms create more social value for stakeholders (Camodeca & Almici, 2021).

By Aghayari et al. (2023), the digital economy heralds a transformative era. As digital technologies evolve, the rapid combination of artificial intelligence (AI), blockchain, cloud computing; additionally, big data are reshaping corporate objectives and governance. This evolution intensifies the competitive landscape for businesses. The related researchers define 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 (Niu et al., 2022). Timchenko et al. (2024) also found that this process entails a comprehensive overhaul of a firm's internal control environment and is a strategic initiative. A key focus of DT is leveraging digital tools to redefine value propositions for customers, as well as to enhance interactions and collaborations with them.

According to Kwilinski et al. (2023), DT is not only an emerging asset for enterprises facing challenges in sustainable development and global economic frameworks, but also a key driving force in this context. It provides enormous potential for sustainable growth by promoting innovation, improving resource efficiency, and reducing carbon emissions (Buallay & Al Marri, 2022). However, the process of DT is also accompanied by concerns about the potential adverse effects on ESG performance (Alkaraan et al., 2022), such as

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the contribution of technology-related hardware production, operation, and disposal to global greenhouse gas emissions (Esmaeilian et al., 2024). Although extensive research has been conducted in academia on the relationship between DT and ESG performance (Mohamed & Saad, 2022), these studies often focus on their general impacts on economic growth, corporate governance, performance, and innovation efficiency, with insufficient exploration of their specific impacts and mechanisms in promoting ESG performance. Specifically, existing literature on how DT affects ESG performance through promoting innovation efficiency, green innovation, and other means often lacks a comprehensive and in-depth analysis of its impact mechanism. For instance, according to the series of research studies by Hu et al. (2022), Zhou et al. (2023), and Zhao et al. (2022), although many studies have explored the influencing factors of green innovation efficiency from the perspectives of environmental regulation, industrial agglomeration, and institutional environment, there is a relative lack of research on how DT specifically affects ESG performance through these factors. In addition, there is a clear lack of research on how technological innovation and financial constraints play a role in the DT process, and how these factors further affect a firm's ESG performance. Therefore, this study aims to fill this research gap by delving into the specific impact mechanisms of DT on ESG performance, especially the roles of technological innovation and financial constraints, and how these factors work together on a firm's ESG performance. This provides a more comprehensive and in-depth perspective for understanding the complex role of DT in the context of sustainable development.

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 corporate ESG performance, with these outcomes demonstrating resilience across various tests. Through mechanism analysis, this article reveals that DT 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 on the ESG performance by using financing constraints, information asymmetry, and technological innovation as mediating variables. Utilizing A-share quoted companies in Shanghai and Shenzhen between 2006 and 2022 as the sample, this article employs Python for web scraping to gauge firms' DT levels and uses Stata for statistical analysis to quantitatively assess its impact on ESG performance and the mechanisms involved, and it also attempts to introduce other control variables such as leverage and return on assets in the model to ensure its practical feasibility. Moreover, this article delves into the primary effect's underlying mechanisms and identifies the heterogeneous effects based on firm size and geographic region to deepen this article and enhance its persuasiveness.

The structure of this article is as follows: Section 2 discusses the review of existing literature and the formulation of hypotheses. Section 3 depicts this article's 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.

2 Literature Review and Hypothesis Development

2.1 Firm DT 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 (Freeman, 2010). 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 (Parvaresh & Amini, 2024). 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 an 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. However, it must be pointed out that implementing ESG activities usually requires financial investment, including expenses for equipment updates, process improvements, and other aspects (Hoang, 2018). Specifically 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, examined by Mahmoudi et al. (2021). Conversely, Taliento et al. (2019) found that 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, leading to some firms hesitating.

Studies by Li et al. (2020) have shown that after DT, 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 (Sepetis et al., 2024). At the same time, DT can also trigger 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 (Wang et al. 2022). While reducing firm costs, it can create more employment opportunities for society, thereby promoting sustainable economic growth. Based on the above analysis and literature experience, this article believes that DT is beneficial for promoting firm ESG performance. Therefore, this article proposes a hypothesis:

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

2.2 Mechanism Analysis

In this section, this article 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

This article believes that reducing financing constraints can improve the degree of DT of firms. Previous studies have indicated that the digital economy lessens the negotiation and opportunity costs associated with corporate debt financing, subsequently lowering firms' financing expenses (Swan, 2019). Additionally, it has been shown that DT significantly lightens the financial load on firms (Alojail & Khan, 2023). Furthermore, the hastening of digitalization aids in establishing and refining the financial credit system. By the research of Zhavoronok et al. (2022), this enhancement can effectively mitigate moral hazards and adverse selection in financial lending, consequently diminishing firms' financial constraints. 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 (Gabor et al., 2019). Based on these observations, the hypotheses are put forward:

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

2.2.2 Information Asymmetry

This article believes that the degree of DT of firms can be improved by eliminating information asymmetry, thereby enhancing their ESG performance. Viewing from a different angle, information asymmetry significantly impacts the enduring growth and sustainability of firms. Nazir et al. (2022) point out that 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. The DT within firms is a pivotal player in diminishing the level of information asymmetry, thereby relieving financial stress and consequently enhancing their ESG performance (Tang, 2022). DT aids firms in bolstering their internal control mechanisms and improving the quality of information exposure, which reduces information asymmetry (Manita et al., 2020).

The prominent advantage of DT lies in the utilization of digital techniques 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 (Nozari & Ghahremani-Nahr, 2021). Conversely, digitalization also helps to eliminate the boundaries between various departments within the firm, break the dilemma of "information silos" (Miller & Tucker, 2014), 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, Guo et al. (2023) found that, 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, thereby attracting more analyst attention and media coverage, enhancing external supervision, and improving the information environment. Based on this, the hypothesis is put forward in this article:

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

2.2.3 Technological Innovation

This article believes that encouraging technological innovation can improve the degree of DT of firms, thereby enhancing their ESG performance. Many industry practices and empirical studies have revealed a stable positive transmission mechanism between DT, technological innovation capabilities, and ESG performance.

According to Dąbrowska et al. (2022), DT is capable of promoting the improvement of technological innovation level in these three aspects. At first, increase investment in research and development. By implementing DT, firms can enhance their research and development capabilities. DT significantly enhances their technological innovation capabilities, investment, and quality, thereby improving the overall level of technological innovation in firms (Yang et al., 2023). Second, improve operational efficiency. DT can promote technological innovation in firms by optimizing the allocation of innovative elements, reducing firm costs, and other means (Su et al., 2023). 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 (Rezaee & Pilevari, 2022). They can optimize information acquisition and product development through new technologies and platforms and enhance their innovation capabilities (Ben Arfi & Hikkerova, 2021). Third, improve the level of human capital. DT enhances employees' ability to access valuable external knowledge and information resources, providing them with opportunities for self-learning and growth. Bansal et al. (2023) found that it helps employees improve their personal human capital level, thereby promoting technological innovation in the firm.

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 (Yurdakul & Kazan, 2020). 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 (Yuan & Cao, 2022). Finally, technological innovation is instrumental in advancing the quality of information exposure and transparency of corporations, which helps to refine their internal governance structures (Karim et al., 2022). Based on this, the hypothesis is put forward in this article:

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

Through this article framework, as depicted in Figure 1, all hypotheses are summarized. First, this article tested the direct effect of DT on corporate ESG performance. Second, this article attempts to investigate the relationship between underlying mechanisms and firm digital transformation (FDT). Then, this article applies empirical analysis to explore the quantitative relationships.

3 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. To ensure an accurate assessment of DT impact on companies, this study excludes certain types of firms: those in the financial sector, firms designated with *ST or ST (which means Special Treatment), and firms with accounting or financial reporting issues.

The methodology for quantifying the frequency of DT within firms is based on the article by Wu et al. (2021). 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 DT

The methodology outlined in the article for assessing the corporate DT 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 the Java PDF Box library, which works as the data repository

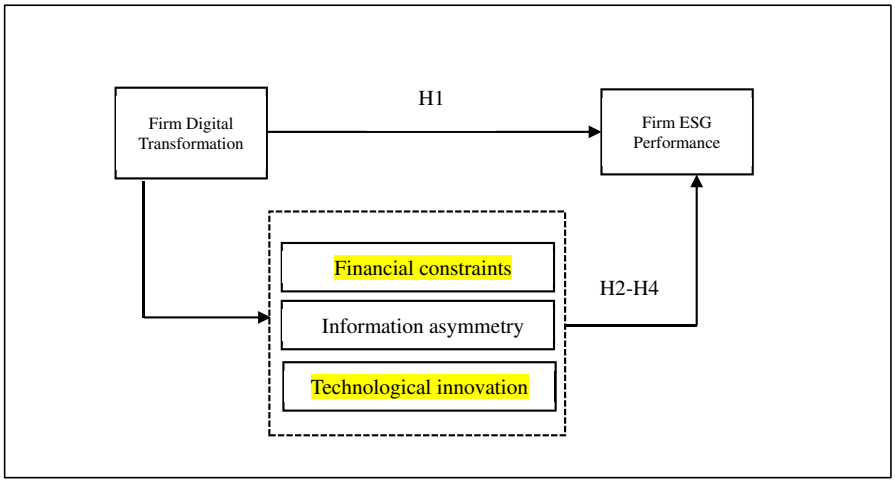

Figure 1: Research framework.

for follow-up keyword filtering. In identifying the keywords indicative of a corporate DT, the article 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. These frequency data, particularly for key technological areas, are collected and aggregated to formulate the final total word frequency metric, which is used to construct an index system to gauge FDT. 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 DT of firms.

3.2.2 Dependent Variable: ESG Performance

To assess the ESG performance of firms, the article 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 (Liu et al., 2024).

Additionally, the article 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 that might arise from omitted variables (Tseng et al. 2024), the article 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).

3.3 Empirical Model

This fixed effect model is created based on 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 the 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 ∑Firm and year ∑Year, along with the random error term ε_{it} (Qi et al. (2024)).

4 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 on 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 FDT stands at about 12.56, with a standard deviation of roughly 33.05, indicating varying levels of DT among Chinese listed firms. The descriptive statistics of control variables corresponds closely to former research studies in the field.

4.2 Baseline Result

Tables 3 and 4 present the Impact of FDT on ESG performance. The univariate regression outcomes are displayed in the first column, controlling solely for corporate fixed effects as well as year-fixed effects. Subsequently, column

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 article 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

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

(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 DT corresponds to a 0.037-unit rise in ESG performance. This suggests that enhancing the extent of DT is capable of positively impacting corporate ESG performance, supporting the core conclusion. It can be inferred that ESG advantages effectively enhance firms' total factor productivity, thereby validating hypothesis H1. According to the results of the collinearity experiment table, there is no collinearity phenomenon in this study.

Table 3: Impact of FDT on ESG performance

	(1) ESG	(2) 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	27,119	27,119
Adj. R^2	0.6538	0.6837
Year FE	Yes	Yes
Firm FE	Yes	Yes

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

Table 4: Collinearity test table

Variable	VIF	1/VIF
Size	1.86	0.538024
ROA	1.74	0.574593
Board	1.45	0.690904
FirmAge	1.44	0.695018
Indep	1.33	0.752758
Cash	1.26	0.794639
Dual	1.11	0.900048
Top1	1.11	0.900467
FDT	1.09	0.917723
Mean VIF	1.36	

4.3 Robustness Test

In order for the robustness of our discoveries, a series of robustness tests were implemented. First, this article replaced the independent variable by introducing dummy variables based on available data. Specifically, this article created the dummy firm digital transformation (DFDT) dummy variable to identify firms implementing DT. The value of this is 1 for companies with non-zero FDT values. The regression outcomes are shown in Table 5, the first column.

Second, this article 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

Table 5: 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	27,119	8,788	7,425	8,421	8,646

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

three aspects: environmental (Env), social responsibility (Soc), along with corporate governance (Gov) (Antolín-López & Ortiz-De-Mandojana, 2023). The regression outcomes are expressed in Table 5, columns (2)–(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 DT significantly enhances firms' ESG performance. It is worth noting that the data show that the environment (Env) is significant at the 1% level, social responsibility (Soc) is significant at the 5% level, and corporate governance (Gov) is significant at the 10% level. According to the analysis in this article, the occurrence of this result may be caused by the following factors.

First, the inherent differences in various indicators may vary. Different ESG components may be influenced by different internal and external factors within the enterprise. Environmental indicators (Env) are often influenced by stricter regulations and policies, such as emission standards and environmental requirements, which may make changes in environmental indicators have a more direct and significant impact on business performance. In contrast, the influencing factors of social responsibility (Soc) and corporate governance (Gov) may be more complex and diverse, leading to differences in statistical significance.

Second, the data quality and availability of various indicators also vary. The environmental data publicly disclosed by firms is often more detailed and standardized than social responsibility and governance data, because environmental information disclosure is often mandatory by laws and regulations. In this case, the quality and reliability of environmental data are relatively high, which may lead to a stronger significance of its statistical test results.

4.4 Mechanism Discussions

For the purpose of coping with the financial constraint effect of FDT, this research uses the CSMAR China Listed Firm Management Dilemma Research Database to obtain the KZ financial constraint index[1] of A-share superior firms and uses its logarithmic processed data (*FC-KZ*) for testing. The specific inspection outcomes are displayed in Table 6. Additionally, it is indicated that the DT role in enlarging corporate financing and eliminating corporate financial constraints to improve ESG performance (Yang & Han, 2023) is supported by H2 in this paper. Therefore, this article finds that financial constraint is one of the underlying mechanisms of the main effect. Hypothesis H2 in this article is valid.

Table 6: Mechanism analysis: channel testing of financial constraint effects in FDT

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

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

For the purpose of dealing with the impact of FDT 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 7. The discoveries in Table 7 indicate that the corporate DT significantly enhances the disclosure of internal control information (Wang et al., 2023). This signifies that FDT 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 (Wang & Hou, 2024). As a result, hypothesis H3 posited in this study is supported.

Table 7: Mechanism analysis: channel testing of information asymmetry effects in FDT

Variables	(2) IC
FDT	0.0038***
	(2.2651)
Control variables	Yes
Firm FE	Yes
Time FE	Yes
Adj. R^2	0.7633
Obs	12,080

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

1 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.

In examining the influence of firm DT on technological innovation, this study leveraged insights from prior literature and accessed pertinent patent classification numbers of A-share quoted companies from China Research Data Service Platform. These data were cross-referenced with the patent classification numbers in the Green Patent List issued by the World Intellectual Property Organization 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 8. In Table 8, 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 (Zhang & Liu, 2023). Consequently, hypothesis H4 posited in this study is upheld.

5 Further Analysis

5.1 Heterogeneity Analysis Based on Firm Size

Lu et al. (2024) point out that the company size plays an irreplaceable part in impacting its capability of effectively enhancing ESG performance. 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 9 reveal that the influence of DT on 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 DT 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 on ESG performance becomes more pronounced.

Based on the above data and existing literature case analysis, this article speculates that large firms have significant advantages in funding, technology, personnel, and other aspects, which can provide sufficient support for innovation activities (Liubkina et al., 2019). 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 (Carfora et al., 2021). Firms can alleviate financial constraints through DT and help establish a good social responsibility image (Wang & Yan, 2023). According to Wu et al. (2023), by improving information control capabilities, information is capable of being improved and processed in time and effectively, lessening the degree of information asymmetry. By improving employee benefits, attracting more innovative talents to

Table 8: Mechanism analysis: channel testing of technological innovation effects in FDT

Variables	(3) ENV
FDT	0.0235***
	(3.6651)
Control variables	Yes
Firm FE	Yes
Time FE	Yes
Adj. R^2	0.8115
Obs	10,289

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

Table 9: Heterogeneity analysis based on firm size

Variables	Firm size		
	Small ESG	Medium ESG	Large 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

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

Table 10: Heterogeneity analysis based on regions

Variables	Regions		
	Eastern ESG	Central ESG	Western 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	16,497	5,017	5,478
Adj. R^2	0.6972	0.5254	0.4115

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

join, and enhancing the degree of technical innovation (Biea et al., 2023). Ultimately, the progression of ESG performance is achieved.

5.2 Heterogeneity Analysis Based on Region

Table 10 presents an analysis based on the distinct features of disparate regions in China, namely the eastern, central, and western regions. The influence of corporate DT on 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 the eastern region is obviously positive at the level of 1%, significant at the 10% level in the central region, and not prominent in the western region. This article posits that the corporate DT in the 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 DT and enhancing ESG performance. Second, the western region experiences a scarcity of high-quality talent, particularly in the digital domain, hindering firms from effectively driving DT 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 DT 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 DT, impacts ESG performance. Conversely, the eastern and central regions exhibit robust market demand, compelling firms to intensify their DT efforts to enhance ESG performance.

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

6 Conclusion

This article on the ESG performance of FDT 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. This article's background encompasses various dimensions, including societal, environmental, economic, and regulatory aspects. Through empirical analysis, this article draws the following conclusions: First, the firm DT significantly enhances ESG performance. Second, DT positively impacts ESG performance by addressing financial constraints, reducing information asymmetry, and fostering firm innovation. By enhancing transparency and efficiency, DT can lower financing costs, thereby enhancing ESG performance.

Based on the aforementioned conclusions, this article puts forward these recommendations: First, from the perspective of expanding financing constraints, firms should explore diverse financing channels, such as bank loans, equity financing, and bond issuance, to secure adequate funds for DT. Developing effective fund utilization strategies can optimize investment returns. Second, from the perspective of reducing information asymmetry, fostering long-term correlations with stakeholders, such as investors, suppliers, customers, employees, and communities, can facilitate the co-creation of ESG goals and action plans. Finally, there are ways to promote technological innovation in firms. Firms should be 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 DT of firms can spur innovation, green technology adoption, and sustainable development, yielding positive impacts on ESG performance.

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

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