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Digital Transformation and Corporate ESG Performance – Evidence from China

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Abstract: The focal point of this paper is to study environmental, social, and governance (ESG) performance consequences of digital transformation for companies, as well as green technological innovation, corporate social responsibility, and internal control as mediating variables. A set of digital transformation indicators was developed utilizing data from 355 listed industrial companies in China between 2011 and 2019 and vector arithmetic. The study's findings suggested that digital transformation has considerably raised ESG performance, with green technological innovation, corporate social responsibility, and internal control as significant mediating variables. The paper has several contributions; for example, it provides theoretical and empirical evidence for ESG improvement in Chinese firms and an essential factor associated with ESG performance, among others. The non-economic impacts of digital transformation on ESG performance are essential insights offered by this study. They also provide insight into these impacts' mechanisms, including green technology, corporate social responsibility, and internal control.

Keywords: digital transformation, corporate ESG performance, green technology innovation, corporate social responsibility, corporate internal control, ESG development

1. Introduction

Recently, there has been an increasing emphasis on environmental changes, pollution incidents, and corporate responsibility, leading stakeholders – including governments, the public, and corporations – to focus more on ESG (environmental, social, and governance) systems [1]. Companies must balance financial performance with environmental sustainability in this era of high-quality economic development. ESG provides a contemporary framework for evaluating corporate sustainability across three dimensions: environmental (E), social (S), and governance (G). Unlike traditional metrics focusing solely on financial performance, ESG includes evaluations of a company's environmental, social, and governance practices [2, 3]. As a result, ESG indicators have gained worldwide recognition as measures of corporate commitment to sustainable development [4].

The public and academic interest in ESG has surged, with extensive discussions centering on ESG behavior, disclosure, and investment. Corporate financial underperformance, natural surplus management, and business strategies can drive improvements in ESG actions [5, 6], and companies in emerging markets may adjust their ESG behavior positively in response to competitive pressures. Furthermore, corporate ESG behavior influences corporate value [7], performance [8, 9], innovation [10], and carbon emissions reduction [11]. Regarding ESG disclosure, various factors like country characteristics [12], corporate traits [13], governance characteristics [14], and climate policies [15] play a significant role. ESG disclosure impacts corporate financing [16], value [17], efficiency [18], and risk [19, 20] ESG investment is influenced by the type of institutional investor [21] and returns on investment [22], and it can affect corporate risk premiums and returns [23].

While extensive research on ESG exists, most studies primarily focus on economic performance, with limited attention given to the impact of corporate digitalization on ESG outcomes. Although some research has explored the connection between digital transformation and ESG performance [24, 25], there remains a lack of detailed understanding regarding the mechanisms and pathways involved. For example, it is still being determined how digital transformation influences explicitly a company's ESG performance and the degree of this impact. In the era of rapid digital economy expansion, businesses must harness the strategic potential of digital transformation. This entails integrating digital technology into various components of business operations, including production, R&D, management, sales, and services. By optimizing internal and external resource allocation, enterprises can enhance their sustainable development capacity, achieving growth that is both environmentally friendly and inclusive [26]. The profound integration of digital technology with the real economy helps lower costs, increase efficiency, fulfill ESG disclosure obligations, and strengthen corporations' capabilities to implement ESG practices [27]. As global concerns about climate change, social issues, and corporate governance grow, companies must align with sustainability trends to remain competitive and gain stakeholder support.

This study investigates enterprise digital transformation's impact and underlying mechanisms on ESG performance. It aims to clarify the internal driving factors and pathways to enhance enterprise ESG performance, providing theoretical and empirical support for ESG development. Using data from 355 listed manufacturing

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companies in China from 2011 to 2019, this paper explores how digital transformation affects ESG performance, identifies the drivers and pathways, and offers evidence for developing corporate ESG practices in China.

The study delves into the link between digital transformation and corporate ESG performance, concentrating on how digitalization can boost ESG practices. It sheds light on the non-economic benefits of digital transformation, extending ESG research within the digital economy and introducing fresh methodologies to enhance corporate ESG outcomes. This research scrutinizes the processes by which digital transformation impacts ESG performance, emphasizing green technology advancements, corporate social responsibility initiatives, and internal governance. Additionally, it aims to deepen insights into the causal connections between digital transformation and ESG performance. The study also presents an innovative method for measuring digital transformation. The study also introduces a new measurement method for digital transformation, inspired by technology spillover research, using vector arithmetic to construct digital transformation indicators, showcasing innovative research methods.

2. Theoretical Background

2.1. Asymmetric information theory

According to Akerlof's [28] theory, the asymmetry of information in market economic activities results in those with better and more reliable information occupying an advantageous position in commodity transactions while others are at a disadvantage, leading to errors in trading decisions. Akerlof's theory of information asymmetry suggests that there can be significant gaps in the information available to various social groups due to their different positions and roles. There are two ways to describe the information gap that results from information asymmetry: quantity and quality. In a market competition, the party possessing more information may have an edge over the other. On the other hand, the party without information may suffer a loss, putting its interests at greater risk. Information asymmetry is prevalent among enterprises, governments, financial institutions, external investors, shareholders, and operators, leading to negative market conditions that seriously affect economic development and stability.

In order to address the challenges posed by information asymmetry, firms need to strengthen monitoring and incentive mechanisms and improve information disclosure mechanisms to meet consumer needs. As a result, the issue of information asymmetry has been a matter of academic interest. With the rapid development of the digital economy, the application of digital technology to break the "data silos," optimizes the internal business management process, making production, sales, internal control, and other aspects more transparent. Digital transformation has to enhance ESG performance through enhanced information transparency, expedited exchange of supply chain information, decreased expenses associated with external stakeholder supervision and governance, and improved quality of internal controls and oversight efficiency.

2.2. Resource-based theory

The resource-based view (RBV) is a theoretical framework that explains why and how a firm's resources and capabilities can contribute to sustainable competitive advantage. From this theoretical perspective, a business's unique resources and capabilities, such as advanced technologies, a deep well of knowledge, a strong brand, and core proprietary technologies, are viewed as the primary source generating its competitive advantages. These resources are not only substantially heterogeneous but they also distinguish each firm in terms of its resources and capabilities. They also possess several distinct characteristics that are complex to replicate and make it difficult for rivals to copy them.

Resource-based Theory (RBT) provides organizations new perspectives on enhancing their ESG performance in digital transformation. RBT argues that a firm's resources and capabilities are the foundation of its competitive advantage. Digital transformation can be considered a strategic resource that enhances a firm's ESG performance by improving resource allocation and strengthening the firm's technological innovation capabilities [24]. Digital transformation requires organizations to innovate at the technological level and to question and realign their resources and capabilities to be more responsive to market changes and social responsibility challenges. Organizations that harness digital capabilities can more effectively identify, develop, and deploy resources that can be used to enhance their ESG performance, such as utilizing big data analytics to improve energy usage and reduce carbon emissions or using social media platforms to improve interaction with consumers and enhance brand social responsibility.

3. Literature Review

3.1. Digital transformation and corporate ESG

Digital transformation, as understood by researchers, encompasses various dimensions and differs from general transformation due to its distinct manifestation modes. General transformation focuses on evolving an organization's development path, mode, and elements, resulting in a shift from one state to another. In contrast, digital transformation employs digital technologies to reconfigure interconnections among subjects, production, business models, and organizational boundaries. This process emphasizes integrating digitalization across organizational modules and the transformative impact of digital information technologies [29, 30]. Current literature examines both the economic and non-economic effects of digital transformation. Economically, digital transformation enhances financial performance [31], innovation [32], stock price stability [33], total factor productivity [34], and green investment efficiency [35]. Non-economically, it improves labor specialization [36], corporate social responsibility [37], and green innovation [38]. Additionally, digital transformation can reduce carbon emissions [39].

The impact of corporate digital transformation on ESG performance is explored primarily through asymmetric information theory and stakeholder theory. From the perspective of asymmetric information theory, digital transformation effectively reduces information asymmetry and increases transparency, thus enhancing corporate ESG performance. Significant investments in environmental and social responsibility might initially seem wasteful, increasing expenses and potentially harming competitiveness and shareholder interests [40]. Many enterprises need help to improve ESG performance due to resource constraints, outdated technologies, and information asymmetry in ESG practices [41]. Artificial intelligence and recognition technologies can analyze vast, multidimensional data regarding a company's finances and activities in real time, improving information quality [42]. Digital transformation facilitates efficient information flow within enterprises, significantly accelerating information processing and analysis [43]. To garner external market support, enterprises timely transmit adequate internal information, helping investors grasp comprehensive

operational, production, and sales data [44]. The application of big data and blockchain technology in digital transformation makes enterprise activities recordable and traceable, improving internal transparency and reducing information asymmetry between stakeholders and enterprises [45].

Viewed through the RBT, digital transformation is the acquisition and application of digital technologies such as big data, cloud computing, the Internet of Things (IoT), and artificial intelligence (AI) to enhance firms' processes and collaborate in the production of competitive products and services. Internal material and human resources can be better managed, and waste can be reduced through optimal supply chains to improve efficiency and reduce ESG performance. Tools such as advanced technologies to build technological innovation capabilities, innovative green products and technologies, and reduce the consumption of resources and pollution in the environment result in improved operational environmental performance. For example, IoT-enabled technologies can monitor production energy consumption and emissions and promptly adjust to prevent ecological impacts [24]. Digital technology also influences the ease and efficiency of allocating internal and human resources for optimal responses to reduce waste and enhance operational efficiency, thereby improving environmental and social performance.

Additionally, it can greenen the information economy by improving information transparency and governance and enhancing stakeholders' trust [46]. Not only does digital strengthen the efficiency of operating remotely, online, offsite, and in diverse locations, but it also changes the organizational culture and behavior that appear with advancing technology and communications while advancing social and governance performance negatively [47]. Finally, the technology transformation allows businesses to access new tools adapted to the competitive market while maintaining the best market with unique resources, capabilities, and competencies to improve the competitive market. In terms of environmental, social, and governance, the business attracts investors and consumers, as well as the availability of green financing and sustainable investment practitioners [25].

Based on this, the following hypothesis is proposed in this paper:

H1: Corporate digital transformation can improve corporate ESG performance.

3.2. The mechanistic impact of corporate digital transformation on corporate ESG performance

Green Technology: Panayotou [48] initiated innovation research, highlighting the positive impact of technological innovation on environmental pollution management [49]. Utilizing digital technologies such as big data and cloud computing helps companies search, integrate, analyze, and make decisions regarding green products and consumption, thereby guiding green innovation directions and potential [50]. For instance, as a leading cloud enterprise service provider in China, UFIDA actively responded to the national "dual-carbon" strategy and integrated ESG concepts with product and service innovation and upgrades. By promoting digital transformation and green technology innovation, UFIDA provides green solutions to all walks of life, thus empowering the economy and society in an all-round green transformation. UFIDA ESG's performance has been outstanding, obtaining an ESG A rating in the past two years, ranking first among A-share software service companies, and shouldering much of the burden. Yang et al. [51] observed that manufacturing intelligence significantly boosts green innovation due to the "technology facilitation effect" and "cost reduction effect" [52]. Digital technology contributes to creating a resource-efficient economic system by mitigating environmental pressures [53], and green innovation can minimize or eliminate pollutant production, enhancing corporate environmental performance [54]. Jalil and Feridun [55] emphasized that developing new technologies is essential in combating pollution.

Social Responsibility: The role of digital transformation in enhancing corporate social responsibility cannot be overstated. It has the potential to innovate business models [56], restructure value chains [57], enhance organizational efficiency [58], and improve corporate reputation [59]. Digital transformation also better captures stakeholder expectations, allocates resources, and customizes production to meet customer needs, increasing satisfaction [60, 61]. In the context of environmental stewardship, digital transformation drives eco-innovation and green diversification, aiding stakeholders in understanding corporate behavior to improve environmental governance [62]. Profit-maximizing objectives and consumer demand for green products compel companies to take environmental responsibility and develop green products and processes [63]. By fulfilling social responsibilities, companies can increase employee motivation and innovation potential, leading to environmentally friendly behaviors [64].

Internal Control: The significance of effective internal control processes in corporate economic activities cannot be overstated [65]. The separation of ownership and management often leads to principal-agent problems, but effective internal controls ensure managers make decisions beneficial to shareholders and corporate value, including active environmental responsibility [41]. Digital technologies improve corporate environmental management by enhancing data quality and accessibility [66]. Chen et al. [67] showed that digital transformation enhances data timeliness and transparency while reducing information costs. Incorporating digital technology into daily operations makes management processes more transparent [68] and changes how corporate information is disclosed to stakeholders [69]. Digital transformation improves process efficiency and resource management, contributing to sustainable economic and environmental performance [70].

Based on this, the following hypotheses are proposed:

H2: Digital transformation can promote corporate ESG performance by driving green technology innovation.
H3: Digital transformation can promote corporate ESG performance by driving corporate social responsibility.
H4: Digital transformation can promote corporate ESG performance by driving corporate internal controls.

4. Methodology

4.1. Sample

This study's robustness is underpinned by a meticulous data collection process. Data from manufacturing companies listed in China's Shanghai and Shenzhen Stock Exchanges were used. After excluding companies with missing data, other types of stocks in their portfolios, and those with special treatment, the final sample comprises 2088 annual observations from 355 companies from 2011 to 2019. Through data analysis from 2011 to 2019, the overall digital level of enterprises and the ES&G scores of enterprises show a significant upward trend. The data show the digital level changed from 4.34 in 2011 to 14.05 in 2019. The data differences between enterprises are enlarging with the increase in standard deviation. Especially after 2015, some enterprises have developed and invested in digitalization very fast. The ES&G score changed from 18.08 in

2011 to 24.43 in 2019. The standard deviation is also gradually increasing. The differences in the data between enterprises in ES&G performance are also widening. The lowest value is relatively stable, and the highest value is rising significantly. Since 2014, some enterprises have made significant progress in ES&G. The analysis shows that enterprises have made progress in digitalization and ES&G. However, considerable differences exist between the digital level and ESG.

The focus on manufacturing companies is due to their significant environmental impact compared to other industries. Manufacturing is a major contributor to environmental pollution, necessitating higher requirements for green innovation and environmental protection. Before 2011, China's digital economy lagged behind the average GDP growth rate. However, since 2011, the digital economy has grown consistently, with its average annual growth rate significantly surpassing GDP growth, becoming a new driving force for China's high-quality economic development. The study period was chosen from 2011 to 2019 to exclude the impact of external uncertainties such as the COVID-19 pandemic, which began in December 2019 and caused significant disruptions to most companies.

4.2. Variable

1) ESG performance. This paper selects the annual ESG scores of Chinese-listed companies published by Murè et al. [71]. The scores range from 1 to 100, weighted by their importance, and are adjusted for each industry, with higher corporate scores indicating better ESG performance. The ESG ratings from Bloomberg have the virtues of being quantitative and transparent, covering the universe of ESG categories, and having a scientific aggregation methodology for the scores. However, the limitations lie in the fact that the ESG scores depend in part on company disclosure, resulting from a somewhat complex scoring aggregation and containing some level of subjectivity. In conclusion, Bloomberg ESG ratings are a very transparent data source that covers all measured aspects, yet it is data-reliant and offers some complexity in the actual scores.
2) Digital spillover (DS). This study adopts the vector operation approach by Jaffe [72, 73] as well as Qiu and Wan [74] to measure digital transformation within the same industry. The method involves the following calculation:

$$W_{i,t} = S_i S'_j \Big/ \sqrt{S_i S'_i * S_j S'_j} \tag{1}$$

$$Digitalspill_{j,t} = \sum_{i \neq j} W_{i,j} * DI_{i,t} \tag{2}$$

According to Wu et al. [43], where $S_i = (S_1, S_2, S_3, S_4, S_5)$ is a row vector formed by adding 1 to the frequency of keywords related to cloud computing technology, blockchain technology, artificial intelligence, big data technology, and digital application technology in the annual reports of the corporation. S'_i is the transposition of S_i. $W_{i,j}$ denotes the digital similarity of corporate i and corporate j in geographical distribution. $DI_{i,t}$ indicates the digital input of corporate i in period t. Using the total investment in digital economy-related assets disclosed in the financial reports of listed companies as a proxy for corporate digitalization investment [75, 76], $Digitalspill_{j,t}$ represents the digital spillover generated by corporation i in period t, measured by the digital similarity and digital input between companies.

3) Mediating variables. Green technology innovation (GTI): Measured by the number of green inventions and patents independently applied by companies, plus one [35, 77]. Social Responsibility (CSR): Measured by social contribution per share. Internal Control (IC): Determined using the DIB internal control disclosure index [63].
4) Control variables. In this paper, we refer to reference [27, 78–80] to include some control variables in the model that may have an impact on the corporate ESG realization (Table 1). The introduction of the control variables mentioned above is in the hope of considering their expected effect on the company's ESG performance. This aims to deeply interpret the relationship between digital transformation and the ESG performance of the companies studied and further improve the research's comprehensiveness and precision.

Table 1
The definition of control variables

Variables	Measurement
Size	Natural logarithm of total assets
Growth	sales growth rate
Lev	Total liabilities/total assets
Top1	Shareholding ratio of top 1
Roa	Net profit / Average total assets
Board	Number of board members
CR	Total current assets/Total current Liabilities

4.3. Models

This paper analyzes the data using a fixed effects model controlling for individuals and years.

$$ESG_{i,t} = \beta_0 + \beta_1 DS_{i,t} + \beta_2 Controls_{i,t} + \lambda_i + \mu_t + \varepsilon_{I,t} \tag{3}$$

To test the mediation mechanism described in the previous section, this study adds green technology innovation, social contribution per share, and internal control disclosure to model (1), where $i = 1,...,n$ and $t = 1,...,t$ stands for corporate and year, Controls is the aforementioned control variable.

5. Empirical Results

5.1. Descriptive statistics

The mean ESG performance score is 21.658 with a standard deviation of 6.811, indicating variability in ESG performance across different manufacturing companies, and suggesting an overall low level of ESG performance. The standard deviation for digital transformation among Chinese manufacturing companies is 2.166. A quantile-based analysis reveals a significant 15.3-fold disparity between the top 25% and bottom 25% of companies in terms of digital transformation, highlighting substantial variations in the digital landscape among different firms. Notably, some variables, such as CSR (corporate social responsibility), growth, and ROA (return on assets), exhibit negative minimum values. This is attributable to the poor growth and profitability of certain companies within the sample. For example, the company with the minimum ROA of −0.016 had a net loss of 6,923,643.6. To preserve data integrity, no conversion of these values to zero was performed (Table 2). In this research, we adopt 39 industrially broad categories to classify the industries,

Table 2
Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ESG	2088	21.658	6.811	9.091	44.628
DS	2088	23.698	2.166	17.279	28.391
GTI	2088	0.837	1.203	0	4.682
CSR	2088	1.569	1.309	–0.599	6.795
IC	2088	35.208	7.571	13	50
SIZE	2088	23.018	1.276	20.361	26.191
LEV	2088	0.460	0.191	0.071	0.893
CR	2088	2.173	2.134	0.383	15.521
GROWTH	2088	0.143	0.301	–0.398	0.833
ROA	2088	0.011	0.014	–0.016	0.065
SHARE	2088	0.371	0.158	0.074	0.793
BOARD	2088	2.197	0.182	1.791	2.708

where the communication and other electronic equipment manufacturing industries and the electrical machinery and equipment manufacturing industries are the two most significant industries in the ranking list.

5.2. Results of baseline regression

The results of the baseline regression analysis are presented in Table 3. Column (1) reflects the regression results with no independent variables, while column (2) shows the regression results with them. Because the regression coefficient is statistically significant at $\beta = 1.061$, $p < .000$, the data support Hypothesis 1.

5.3. Results of robust test

This manuscript employs regression analysis to examine the stability of model outcomes by using a one-year lagged relationship and a replacement for the digital transformation variable method. First, we use one-year-lagged digital choice to investigate whether digital transition results in ESG performance. In this research, the digital measure in Wu et al. [43] was replaced by the logarithmic transformation (lnDT) of digital data from the China Stock Market Accounting Research Database. Table 4 indicates that the regression model's results correspond to the robustness check.

Table 3
Regression results

Variable	(1) TOBINQ	(2)TOBINQ
DS		1.061***
		(6.09)
SIZE	3.929***	1.811***
	(7.54)	(2.89)
LEV	–5.082***	–4.328**
	(–2.99)	(–2.57)
CR	–0.136	–0.741
	(–1.64)	(–0.86)
GROWTH	–0.828*	–0.875**
	(–184)	(–2.00)
ROA	–3.384	0.123
	(–0.27)	(0.01)
SHARE	–3.477	–1.417
	(–1.22)	(–0.51)
BOARD	–1.958	–1.009
	(–1.41)	(–0.75)
_Cons	–60.351***	–40.142***
	(–4.64)	(–2.97)
F	15.12	18.49
Adj.R^2	0.17	0.21

Table 4
Robust test

	(1) ESG		(2) ESG
DS_{t-1}	1.101***	lnDT	1.183***
	(5.70)		(5.50)
SIZE	1.721***	SIZE	3.065***
	(2.48)		(6.12)
LEV	–3.971*	LEV	–4.197***
	(–1.76)		(–2.48)
CR	0.018	CR	–0.107
	(0.15)		(–1.32)
GROWTH	0.465	GROWTH	–0.792*
	(0.74)		(–1.73)
ROA	10.071	ROA	1.659
	(1.64)		(0.14)
SHARE	–0.558	SHARE	–1.952
	(–0.19)		(–0.73)
BOARD	–1.989	BOARD	–1.302
	(–1.40)		(–0.99)
_Cons	–37.409***	_Cons	–44.465***
	(–2.46)		(–3.61)
F	12.31	*F*	19.79
Adj. R^2	0.19	Adj. R^2	0.21

5.4. Results of endogeneity analysis

In the empirical testing (Table 5), we did find that the allocation between enterprise digital transformation and ESG performance is bidirectional and recognition is sought endogeneity. We conducted the 2SLS approach and used one-year lagged digital transformation as the instrumental variable to solve this problem. Table 5 shows the results of the 2SLS. The first column shows the instrumental variables significantly connected to the endogenous variables and the weak identification test verifies the validity of the instrumental variables. As anticipated, the second column of Table 5 shows that digital transformation significantly affects ESG performance ($p < 0.01$), even after taking care of an endogeneity problem with the instrumental variables.

The second method that researchers have used is propensity score matching (PSM). Following He and Liu [75], the sample will be divided into high and low digital transformation groups, and new variables called digital group (DG) will be created. PSM involves the nearest neighbor matching approach to find control samples from the treatment group and use control variables in Section 3. These control variables will be used to find an adequately matched sample, and after the balance test, the matching samples will be run through the regression tests (Table 5). We will see that digital transformation will still affect ESG performance in the matched regression results.

$$Digitalaccept_{i,t} = \sum_{i \neq j} W_{i,j} * DI_{j,t} \quad (4)$$

Highlevel = $Digitalspill_{j,t} \geq Digitalaccept_{i,t}$
Lowlevel = $Digitalspill_{j,t} < Digitalaccept_{i,t}$

Table 5
Endogeneity test

	(1) DS	(2) ESG		(3) Before PSM	(4) After PSM
DS_{t-1}	0.895***		DG	1.811***	2.157***
	(97.65)			(0.31)	(0.42)
DS		0.581***	SIZE	1.926***	1.675***
		(4.87)		(0.16)	(0.35)
SIZE	0.109***	1.895***	LEV	–4.644***	–6.194***
	(6.49)	(9.24)		(1.01)	(1.92)
LEV	0.079	–6.461***	CR	–0.166***	–0.676***
	(0.68)	(–4.79)		(–0.47)	(0.16)
CR	0.006	–0.303***	GROWTH	–0.471	0.641
	(0.67)	(–2.66)		(0.46)	(0.86)
GROWTH	0.351***	–0.048	ROA	–29.547***	–17.728
	(7.40)	(–0.09)		(10.66)	(18.34)
ROA	1.783	–25.874	SHARE	1.268	0.669
	(1.58)	(–1.96)		(1.05)	(1.86)
SHARE	–0.057	1.822	BOARD	2.733***	2.780**
	(–0.65)	(1.76)		(0.74)	(1.25)
BOARD	0.005	2.465***	_Cons	–26.998***	–20.359***
	(0.08)	(2.87)		(3.56)	(7.73)
Underidentification test		1338.827***			
Weak identification test		9535.311***			
Adj. R^2	0.94	0.18	Adj. R^2	0.32	0.27
industry	YES	YES	industry	YES	YES
year	YES	YES	year	YES	YES

5.5. Results of heterogeneity analysis

The study looks into how the lasting impact of digital transformation on firm ESG performance changes when ownership traits are taken into account. We present test results in Table 6, columns (1) and (2). When further broken down by ownership, the interactive regression states that digital transformation significantly impacts ESG performance measures for state-owned firms (β = 1.269, p < 0.000), as well as non-state-owned firms (β = 0.805, p < 0.000). State-owned firms showed less improvement in ESG performance, meaning they are more likely to adopt digital transformation to improve ESG.

Moreover, we also run a regional heterogeneity test for businesses from the Western, Central, and Eastern regions. The impact of the digital transformation on the ESG performance in the Eastern, Central, and Western regions is presented in Table 6, column (3), column (4), and column (5), respectively. Nevertheless, Western firms must strengthen their digital transformation to offset their ESG performance.

5.6. Results of mediating analysis

Following Sobel [81] as well as Baron and Kenny [82], we established the mediation effect of green technical innovation, social contribution value per share, and corporate internal control. We tested the direction and significance of regression coefficients using regression analysis (see Table 7). The increase in corporate green technology innovation has a digital transition regression coefficient of 0.179 at 1%, as shown in Table 7. In column (3), the digital transition and green technology innovation coefficients come in at 0.711 and 0.901, both significant at 1%, and the indirect effect is 0.161, representing 18.5% of the total impact, indicating a partial mediation effect. In the middle-step mediation with social contribution value per share, in column (5), the digital transition coefficient is 0.242 (see Table 7, columns (4), (5), and (6)). The 1% increase in social contribution per share is important. In column (6), the digital transition and social contribution value per share coefficients are 0.662 and 0.871, both significant at 1%, and the indirect effect is 0.193, representing 24.1% of the total effect, indicating a partial mediation effect. Finally, in the last step of the mediation, with corporate internal control levels (Table 7, columns (7), (8), and (9)), we found that the digital transition coefficient is 0.268 and is significant at 1%. In column 9, the digital transition and internal control level coefficients are 0.855 and 0.069, both significant at 1%, and the indirect effect is 0.060, demonstrating a 1.2% increase; the weak mediation suggests that the effect is insignificant.

6. Discussion

This study elucidates the impact of digital transformation on ESG performance through the lenses of asymmetric information theory, RBT, and sustainable development.

Firstly, Table 4 confirms Hypothesis 1 [24, 25, 80, 83–86]. External investors use ESG performance to assess investment risks, economic sustainability, and corporate social responsibility [87]. Furthermore, digitalization, a prerequisite for sustainable

Table 6
Heterogeneity test

	(1) SOE	(2) NON-SOE	(3) EASTERN	(4) CENTRAL	(5) WESTERN
DS	1.269***	0.805***	0.994***	1.388***	0.838**
	(5.70)	(2.68)	(4.47)	(3.80)	(1.94)
SIZE	1.239*	2.734***	1.967***	2.203***	1.366
	(1.68)	(2.77)	(2.45)	(2.87)	(0.66)
LEV	0.282	–9.145***	–6.365***	–3.841**	1.184
	(0.11)	(–3.81)	(–3.59)	(–1.04)	(0.23)
CR	–0.121	–0.168	–0.067	–0.381	–0.125
	(–1.25)	(–1.49)	(–0.68)	(–2.32)	(–0.61)
GROWTH	–0.655	–1.237***	–1.252***	0.234	–1.245*
	(–0.97)	(–3.59)	(–2.71)	(0.23)	(–1.72)
ROA	13.607	–23.039	–14.494	54.804	4.864
	(0.85)	(–1.21)	(–1.09)	(1.56)	(0.19)
SHARE	–4.616	0.924	–2.226	–0.511	9.264
	(–1.14)	(0.22)	(–0.70)	(–0.10)	(0.86)
BOARD	–3.175	1.391	–1.986	2.261	–1.584
	(–1.63)	(0.76)	(–1.10)	(0.86)	(–0.41)
_Cons	–27.911**	–58.562***	–38.615**	–65.142***	–29.188
	(–1.83)	(–2.77)	(–2.38)	(–2.97)	(–0.58)
F	9.66	9.93	16.05	6.73	1.22
Adj. R^2	0.21	0.25	0.25	0.25	0.11

development, broadens the scope and depth of information access, optimizing processes for information collection, processing, analysis, and application [88–90]. This reshaping of corporate-stakeholder interactions substantiates information asymmetry and stakeholder theories, promoting transparency and reciprocal value creation [91].

Secondly, Table 7 validates Hypotheses 2, 3, and 4, revealing three ways digital transformation influences ESG performance: Green technology innovation, corporate social responsibility, and internal control levels. Notably, green technology innovation acts as a mediator in this relationship, as digital transformation facilitates the development of environmentally friendly technologies and products [92–95]. Corporations leverage advanced digital technologies to enhance production processes, improve design efficiency, and control pollution, fostering green innovation and reinforcing a positive public image [96–98].

Corporate social responsibility (CSR) also mediates the link between digital transformation and ESG performance [42, 99, 100]. Digital transformation enhances CSR by improving capital mobility, achieving financial synergies, and increasing disposable capital, leading to more significant ESG investments and improved performance. The increased visibility provided by digital technologies ensures that CSR efforts are more effectively communicated to stakeholders, fostering a positive corporate image and stronger stakeholder relationships [101]. CSR practices also boost employee organizational identity and motivation for pro-social behavior while meeting consumer demand for green products and a quality ecological environment [102].

Hypothesis 4 is supported by the findings that internal control quality mediates the relationship between digital transformation and ESG performance [27, 91, 94]. Adequate internal controls mitigate managerial opportunism and facilitate decision-making that supports long-term corporate interests, enhancing environmental investment and corporate sustainability [103–105]. Digital technologies unify management information processes, improving transparency and responsiveness, which bolsters stakeholder understanding of corporate environmental commitments [94, 103, 106, 107].

Finally, heterogeneity tests indicate that ownership nature and geographical location affect ESG performance. State-owned enterprises (SOEs) outperform non-SOEs due to better resource and policy support and the effectiveness of national policies such as digitalization and green development [108]. Enterprises in the western regions lag in ESG performance due to economic and infrastructure disparities compared to the eastern and central regions. Digital transformation can foster equitable development in the Western region, narrowing gaps and promoting sustainable economic growth.

7. Conclusion

This research identifies critical findings regarding the relationship between corporate digital transformation and ESG performance, focusing on the contributions of green technology innovation, social responsibility, and internal control mechanisms. The study's outcomes demonstrate that digital transformation profoundly affects corporate ESG performance. Additionally, the role of green technology innovation and social responsibility is significant in mediating the impact of digital transformation on ESG performance. Even though the influence of internal control is less pronounced, it remains crucial. The impact of digital transformation on ESG performance is uneven, with variations observed among state-owned enterprises (SOEs), non-SOEs, and companies across different regions, showing a less significant effect in non-SOEs and Western companies.

The theoretical implications of this study include constructing a digital transformation index system for manufacturing corporations using vector arithmetic. This approach provides a detailed

Table 7
Mediating effect of CCS

	(1) ESG	(2) GTI	(3) ESG		(4) ESG	(5) CCS	(6) ESG		(7) ESG	(8) IC	(9) ESG
DS	0.873***	0.179***	0.711***	DS	0.873***	0.242***	0.662***	DS	0.873***	0.268***	0.855***
	(12.80)	(14.29)	(10.09)		(12.80)	(18.22)	(9.14)		(12.80)	(3.54)	(12.52)
GTI			0.901***	CCS			0.871***	IC			0.069***
			(7.67)				(7.86)				(3.3)
_Cons	−948.345 ***	67.783 ***	−1009.438 ***	_Cons	−948.345 ***	131.836 ***	−1063.172 ***	_Cons	−948.345 ***	−2059.43 ***	−805.704 ***
	(−8.51)	(3.31)	(−9.16)		(−8.51)	(6.07)	(−9.59)		(−8.51)	(−16.59)	(−6.81)
Control	Yes	Yes	Yes	Control	Yes	Yes	Yes	Control	Yes	Yes	Yes
F	133.67	69.57	117.75	*F*	133.67	111.06	118.63	*F*	133.67	130.96	103.92
Adj.R^2	0.16	0.09	0.18	Adj. R^2	0.16	0.13	0.18	Adj. R^2	0.16	0.15	0.16

examination of corporate digitization theory. It expands the research scope of the digital economy, offering theoretical support for corporate digital transformation and contributing significantly to existing literature. By integrating digital transformation into the study of corporate ESG performance, this research uncovers new pathways for improving ESG performance and delves into the non-economic effects of digital transformation. Traditional ESG research typically focuses on environmental, social, and governance aspects; this paper introduces digital transformation as a new perspective for enhancing corporate ESG performance.

Additionally, this study elucidates how green technology innovation, social responsibility, and internal control mediate the relationship between digital transformation and ESG performance, providing a novel interpretation of this link. This mechanism shows how digitization promotes environmental sustainability, social responsibility, and internal control optimization, ultimately leading to better ESG performance. The research offers new theoretical insights and practical guidance for digital transformation and ESG management.

Based on the findings, the paper presents several practical recommendations: Corporations should leverage the opportunities offered by the digital economy and intensify their digital transformation efforts, integrating digital technologies into all aspects of production and operation. By profoundly integrating digital technology, companies can optimize production processes, improve efficiency, reduce costs, enhance market competitiveness, promote green technology innovation, achieve sustainable production, and contribute to environmental protection. For sustainable growth, non-state-owned enterprises and publicly traded manufacturing companies in the Western regions should actively embrace digitalization and enhance their ESG practices. These practices will bolster their brand image, community reputation, and market competitiveness. Combining digital transformation and ESG standards will help these companies address resource-related issues and adapt quickly to changing consumer demands, leading to sustainable long-term growth. Additionally, government departments should promote integrating the digital economy with the real economy, accelerate the development of digital infrastructure, create a favorable macro environment, and support the swift implementation of digital transformation in corporations. To further enhance corporate ESG performance and foster a collaborative governance environment between corporations and the government, necessary guarantees should be provided.

Looking ahead, this paper paves the way for future research by suggesting exciting directions. These include exploring the varied approaches and contexts across different countries and regions in promoting sustainable business growth. Comparative studies could analyze the successes and policies of other nations, drawing on their experiences and insights to provide valuable recommendations for global sustainable development.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Wenxin Zhang: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft. **Xiangyu Li:** Software, Writing – review & editing.

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