

Digital-Intelligent Transformation and Corporate ESG Performance: The Mediating Roles of Internal Control Quality and Financing Constraints

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Abstract. With the rapid development of digital technologies, digital-intelligent transformation has become an important pathway for firms to achieve sustainable development. This study investigates the impact of digital-intelligent transformation on corporate ESG performance and further examines the underlying mechanisms through which this relationship operates. Using panel data from Chinese A-share listed companies during 2010–2023, this study constructs a two-way fixed effects model to empirically examine the relationship between digital-intelligent transformation and corporate ESG performance. The findings demonstrate that digital-intelligent transformation significantly improves corporate ESG performance, indicating that digital technologies can effectively promote firms' sustainable development. Mechanism analyses reveal that internal control quality and financing constraints serve as important transmission channels: digital-intelligent transformation enhances ESG performance by strengthening internal governance capabilities and alleviating financing constraints. Further robustness tests, including alternative measurements of key variables and different sample specifications, confirm the reliability of the results. Additional heterogeneity analyses indicate that the positive effect of digital-intelligent transformation on ESG performance varies across ownership structures and industry characteristics. This study contributes to the literature on digital transformation and corporate sustainability by revealing the governance and resource allocation mechanisms through which digital technologies facilitate ESG improvement. The findings provide practical implications for firms and policymakers seeking to promote sustainable development through digital innovation.

Keywords: Digital-intelligent transformation; Corporate ESG performance; Internal control quality; Financing constraints; Sustainable development; Corporate governance.

1. Introduction

The report delivered by General Secretary Xi Jinping at the 20th National Congress of the Communist Party of China explicitly emphasized the need to accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy, while advancing green and low-carbon development through coordinated efforts to reduce carbon emissions, control pollution, expand ecological conservation, and promote economic growth. In 2025, the Cyberspace Administration of China and nine other government departments jointly issued the *Key Points for Promoting Coordinated Digital and Green Transformation Development*. Subsequently, the 2026 Government Work Report further highlighted the need to deepen the Artificial Intelligence Plus initiative and promote the profound integration of digital technologies with green and low-carbon development. Through a series of strategic policy initiatives, the Chinese government has strengthened the role of digitalization in driving green development, facilitating the deep integration of intelligent digital transformation and corporate sustainability.

In recent years, China's economy has achieved remarkable progress; however, challenges related to environmental governance, social responsibility, and corporate governance have increasingly emerged. Guided by the principles of sustainable development, accelerating the green transformation of economic development models, improving corporate ESG governance systems, and achieving high-quality and sustainable growth have become urgent priorities. Enterprises serve not only as the core actors of economic activities but also as the micro-level foundations for achieving synergy between digital-intelligent transformation and ESG development. At the critical juncture of

concluding the 14th Five-Year Plan and planning the 15th Five-Year Plan, investigating the impact of corporate digital-intelligent transformation on ESG performance and identifying its underlying mechanisms—particularly from the perspectives of accounting information quality and resource allocation—carry significant theoretical value and practical implications for advancing sustainable corporate development in the digital era.

2. Literature Review and Hypothesis Development

2.1. Digital-Intelligent Transformation and Corporate ESG Performance

Corporate ESG performance is an important indicator for evaluating firms' sustainable development capabilities, reflecting their comprehensive performance in environmental protection, social responsibility fulfillment, and corporate governance enhancement. Unlike traditional financial performance measures, ESG emphasizes firms' long-term value creation capabilities and focuses on how firms achieve a balance between economic objectives and social value creation through efficient resource allocation, improved governance effectiveness, and responses to stakeholder demands[1,2].

With the rapid advancement of digital technologies, digital-intelligent transformation has gradually become a critical driver of corporate sustainable development. Digital technologies provide new technological foundations for ESG practices by enhancing information processing capabilities, optimizing operational processes, and strengthening organizational coordination. On the one hand, emerging technologies such as big data, artificial intelligence, and intelligent manufacturing enable firms to achieve more precise management of production processes, improve resource utilization efficiency, and reduce energy consumption and pollutant emissions, thereby enhancing environmental performance[3]. On the other hand, digital transformation can improve corporate information transparency and governance efficiency, enabling firms to more effectively identify and respond to environmental and social responsibility requirements[4].

From the perspective of stakeholder theory, digital-intelligent transformation facilitates information exchange between firms and key stakeholders, including investors, consumers, and regulatory authorities. By reducing information asymmetry and improving the quality of ESG-related information disclosure, digital transformation encourages firms to undertake greater social responsibility. Meanwhile, digital technologies promote organizational restructuring and managerial innovation, enhancing operational efficiency and strengthening firms' capabilities for sustainable development^[5]. However, some studies suggest that digital transformation may also generate short-term resource crowding-out effects. Investments in digital infrastructure, technological upgrading, and organizational restructuring require substantial financial and managerial resources, which may temporarily constrain firms' investments in green governance and social responsibility initiatives[6]. Therefore, the relationship between digital-intelligent transformation and corporate ESG performance requires further empirical investigation.

Based on the above discussion, this study proposes the following hypothesis:

H1: Digital-intelligent transformation significantly improves corporate ESG performance.

2.2. Digital-Intelligent Transformation, Internal Control Quality, and Corporate ESG Performance

Internal control quality is a fundamental component of corporate governance systems and plays an essential role in ensuring standardized operations and improving resource utilization efficiency. According to information asymmetry theory, information gaps between corporate managers and external stakeholders may induce managerial opportunism, such as selective disclosure of environmental information and insufficient fulfillment of social responsibilities. Therefore, improving internal control quality can enhance corporate transparency and promote substantive ESG practices. Digital-intelligent transformation can reshape firms' internal control systems through the application of digital technologies. On the one hand, digital systems facilitate automated business processes and real-time information sharing, improving the accuracy, completeness, and timeliness

of operational data. On the other hand, intelligent management tools strengthen risk identification and dynamic monitoring capabilities, reduce reliance on human intervention, and improve the effectiveness of internal control mechanisms [7].

Prior studies have demonstrated that high-quality internal control mechanisms strengthen corporate monitoring systems, mitigate managerial opportunistic behavior, and encourage firms to fulfill environmental and social responsibilities [8, 9]. As internal control quality improves, ESG-related information can more accurately and comprehensively reflect firms' sustainable development performance. Meanwhile, enhanced internal governance capabilities encourage firms to proactively engage in green innovation, employee protection, and governance optimization. Therefore, internal control quality may serve as an important transmission mechanism through which digital-intelligent transformation influences corporate ESG performance.

Accordingly, this study proposes the following hypothesis:

H2: Digital-intelligent transformation promotes corporate ESG performance by improving internal control quality.

2.3. Digital-Intelligent Transformation, Financing Constraints, and Corporate ESG Performance

Corporate ESG initiatives are typically characterized by long investment cycles and delayed returns. Activities such as green technology innovation, environmental protection investment, employee welfare improvement, and governance system enhancement require continuous and stable financial support. Therefore, financing constraints represent a critical factor limiting corporate ESG development. According to the resource-based view, sustainable competitive advantages arise from firms' ability to effectively acquire and allocate critical resources. Digital-intelligent transformation can improve firms' external financing environments by enhancing information transparency, reducing transaction costs, and optimizing operational efficiency. On the one hand, digital technologies improve the availability and quality of corporate information, allowing financial institutions and investors to more accurately evaluate firm risks and reduce information asymmetry during financing processes. On the other hand, digital management systems improve capital utilization efficiency and optimize internal resource allocation [10].

Existing research suggests that firms facing lower financing constraints possess greater resources for long-term strategic investments and are therefore more likely to allocate capital toward environmental governance, social responsibility initiatives, and corporate governance improvement. Accordingly, digital-intelligent transformation may facilitate ESG performance enhancement by alleviating financing constraints and providing firms with stronger resource support [11, 12].

Based on this reasoning, the following hypothesis is proposed:

H3: Digital-intelligent transformation promotes corporate ESG performance by alleviating financing constraints.

3. Research Design

3.1. Data Sources

This study employs a micro-level panel dataset of Chinese A-share listed firms from 2010 to 2023 as the initial sample for empirical analysis. Several procedures are implemented to ensure data reliability and robustness. First, firms in the financial and insurance industries are excluded, as well as firms with abnormal operating conditions, including those designated as Special Treatment (ST or *ST) and Particular Transfer (PT) firms. Second, observations with missing values in key variables or abnormal data records are removed. Third, to mitigate the potential influence of extreme values, continuous variables are winsorized at the 1% level in both tails.

After the data-cleaning process, the final sample consists of 49,996 firm-year observations. The explanatory variable, digital-intelligent transformation, is constructed based on information extracted from annual reports of listed firms. The dependent variable, corporate ESG performance, is obtained

from the Huazheng ESG Rating Database. The mediating variables, internal control quality and financing constraints, are collected from the DIB Internal Control Database and the CSMAR (China Stock Market & Accounting Research Database), respectively. Control variables and other financial and corporate governance indicators are also obtained from the CSMAR database. Industry classifications follow the Guidelines for the Industry Classification of Listed Companies issued by the China Securities Regulatory Commission (CSRC, revised in 2012).

3.2. Variable Selection

3.2.1. Independent Variable

This study constructs a keyword dictionary for digital-intelligent transformation from five dimensions: artificial intelligence, big data, cloud computing, blockchain, and digital technology applications. Python-based text-mining techniques are employed to conduct word segmentation and frequency analysis on the Management Discussion and Analysis (MD&A) sections of listed firms' annual reports. To alleviate the influence of right-skewed distribution, the natural logarithm of the total keyword frequency plus one is used as the measurement of digital-intelligent transformation.

3.2.2. Dependent Variable

Following existing studies, this study adopts the average Huazheng ESG rating score (HZ_ESG_avg) as the core measure of corporate ESG performance. Specifically, the Huazheng ESG ratings are transformed into numerical scores, with AAA, AA, ..., and C assigned values of 9, 8, ..., and 1, respectively. The annual arithmetic mean of the ESG rating score is then calculated to represent the overall ESG performance of each firm.

3.2.3. Mediating Variables

Based on prior literature, this study selects two mediating variables that are theoretically associated with digital-intelligent transformation: internal control quality (ICQ) and financing constraints (KZ). Internal control quality is measured using the DIB Internal Control Index, which is logarithmically transformed. A higher value of ICQ indicates stronger internal control quality. Financing constraints are measured using the Kaplan–Zingales (KZ) index, where a higher KZ value indicates a higher level of financing constraints faced by firms.

3.2.4. Control Variables

Following previous studies, this study incorporates firm-level, corporate governance-level, and macro-level control variables. Firm financial characteristics include sales growth (Growth) and leverage ratio (Lev). Corporate governance characteristics include managerial ownership (Mown), board size (DirectorNumber), the proportion of independent directors (IND), CEO duality (Dual), and the ownership concentration of the top ten shareholders (TO10). In addition, industry fixed effects and year fixed effects are included to control for unobservable time-invariant industry characteristics and macroeconomic shocks.

3.3. Model Specification

To examine the impact of DT on corporate ESG performance, this study constructs a two-way fixed effects model as the baseline specification.

$$ESG_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \sum \alpha_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Where $ESG_{i,t}$ represents the ESG performance of firm i in year t , and $DT_{i,t}$ denotes the level of digital-intelligent transformation. $Controls_{i,t}$ represents a vector of control variables, including Growth, Lev, Mown, DN, IND, Dual, and TO10. μ_i and λ_t represent firm fixed effects and year fixed effects, respectively. $\varepsilon_{i,t}$ is the error term. The coefficient of interest is α_1 , which captures the impact of DT on ESG.

To further examine the underlying mechanisms through which DT affects ESG, this study employs a mediation analysis framework and investigates the mediating roles of ICQ and KZ. Following the conventional mediation approach, the following models are constructed:

First, the mediating effect of ICQ is examined using the following equations:

$$ICQ_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \sum \beta_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

$$ICQ_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \sum \beta_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

Second, to test whether KZ serves as another transmission mechanism, the following models are estimated:

$$KZ_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \sum \beta_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

$$KZ_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \sum \beta_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (5)$$

Where ICQ and KZ represent the mediating variables. A significant coefficient of DT in the mediator models indicates that DT affects the corresponding mediating mechanism, while a significant coefficient of the mediator variable in the ESG model suggests the existence of a transmission channel.

4. Empirical Analysis

4.1. Descriptive Statistics of Main Variables

Table 1 reports the descriptive statistics of the main variables. The results show that the mean value of firms' digital-intelligent transformation level is 1.5105, with a standard deviation of 1.4237, and the minimum and maximum values are 0 and 5.1930, respectively, indicating significant differences in digital-intelligent transformation levels among firms. The mean value of corporate ESG performance is 3.9472, with a standard deviation of 1.1404, ranging from 0 to 6.2500, suggesting that the overall ESG performance of sample firms remains at a moderate level with certain variations across firms. The mean value of internal control quality is 5.5939, with a standard deviation of 2.2242, while the financing constraint indicator has a mean value of 0.4958 and a standard deviation of 0.2197. Both mediating variables exhibit sufficient variation and fall within reasonable ranges. Regarding the control variables, the average sales growth rate is 15.1751%, with a relatively large standard deviation of 46.0737, reflecting substantial heterogeneity in firms' growth performance. The mean leverage ratio is 42.4492%, indicating a moderate level of financial leverage among sample firms. Managerial ownership averages 13.4627%, while board size and the proportion of independent directors have mean values of 8.3199 and 37.1992, respectively. The average value of CEO duality is 0.2927, indicating that nearly 29.27% of firms adopt a dual leadership structure. The ownership concentration of the top ten shareholders has a mean value of 58.2804%, suggesting relatively concentrated ownership structures among Chinese listed firms. Overall, the descriptive statistics indicate that all variables exhibit adequate variation and remain within acceptable ranges, providing a reliable foundation for subsequent regression analyses.

Table 1. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
DT	49996	1.5105	1.4237	0.0000	5.1930
ESG	49996	3.9472	1.1404	0.0000	6.2500
ICQ	49996	5.5939	2.2242	0.0000	6.7217
KZ	49996	0.4958	0.2197	0.0000	0.8243
Growth	49996	15.1751	46.0737	-62.7818	310.9305
Lev	49996	42.4492	21.6577	5.0561	97.8537
Mown	49996	13.4627	19.4900	0.0000	68.3983
DN	49996	8.3199	1.8705	0.0000	14.0000
IND	49996	37.1992	6.7953	0.0000	57.1400

Dual	49996	0.2927	0.4550	0.0000	1.0000
TO10	49996	58.2804	15.6930	21.8444	90.5345

The correlation analysis and multicollinearity tests were conducted before the regression analysis. The results show that digital-intelligent transformation is significantly positively correlated with corporate ESG performance, providing preliminary evidence supporting the positive relationship between digital-intelligent transformation and ESG performance. The correlation coefficients among the main variables are generally below 0.7, with the highest correlation coefficient being 0.6632 between internal control quality and financing constraints, indicating that there is no severe linear correlation among the variables. Furthermore, the variance inflation factor (VIF) test results demonstrate that the maximum VIF value is 2.1956 and the mean VIF value is 1.3686, while all VIF values remain below the commonly accepted threshold of 10. These results suggest that multicollinearity is not a serious issue in this study, and the selected variables are suitable for subsequent regression analysis.

4.2. Baseline Regression Results

Table 2 presents the baseline regression results examining the impact of DT on ESG. The results show that the coefficient of DT is positive and statistically significant across all specifications. Specifically, in Model (1), without including control variables and fixed effects, the coefficient of DT is 0.1127 and significant at the 1% level, indicating that higher levels of DT are associated with improved ESG performance. After gradually introducing control variables, industry fixed effects, and year fixed effects, the coefficient of DT remains positive and significant. In Model (3), which incorporates all control variables, industry fixed effects, year fixed effects, and robust standard errors, the coefficient of DT is 0.0923. These results demonstrate that DT significantly promotes ESG, supporting Hypothesis 1.

Table 2. Baseline Regression Results.

	(1)	(2)	(3)
	ESG	ESG	ESG
DT	0.1127*** (31.785)	0.1051*** (32.019)	0.0923*** (8.568)
Growth		-0.0004*** (-4.086)	-0.0003** (-2.311)
Lev		-0.0062*** (-27.047)	-0.0069*** (-8.683)
Mown		0.0031*** (11.705)	0.0031*** (5.852)
DirectorNumber		0.1585*** (63.112)	0.1611*** (28.221)
IND		0.0485*** (70.480)	0.0474*** (50.712)
Dual		-0.0320*** (-3.005)	-0.0350** (-2.310)
TO10		0.0052*** (16.985)	0.0054*** (6.975)
Constant	3.7769*** (513.036)	0.5992*** (15.024)	0.6592*** (10.998)
N	49,996	49,996	49,996
R-squared	0.020	0.182	0.221
Industry	NO	NO	YES
Year	NO	NO	YES

*** p<0.01, ** p<0.05, * p<0.1

Regarding the control variables, Growth is negatively associated with ESG, suggesting that rapid business expansion may not necessarily contribute to sustainable development in the short term. Lev

also shows a significant negative relationship with ESG, indicating that higher financial leverage may constrain firms' investment in ESG-related activities. In contrast, Mown, DN, IND, and TO10 are positively associated with ESG, suggesting that stronger corporate governance mechanisms contribute to improved ESG performance. Dual exhibits a negative relationship with ESG, implying that the concentration of managerial power may weaken governance effectiveness. Furthermore, the explanatory power of the models improves substantially after incorporating control variables and fixed effects. The R-squared increases from 0.020 in Model (1) to 0.221 in Model (3), indicating that the inclusion of additional controls and fixed effects enhances the explanatory capability of the model. Overall, the baseline regression results provide robust evidence that DT has a significant positive effect on ESG, thereby supporting Hypothesis 1.

4.3. Robustness Tests

To further examine the reliability of the baseline regression results, this study conducts three additional robustness tests by replacing the dependent variable, replacing the measurement of DT, and changing the sample period. The results are reported in Table 3.

First, this study replaces the original measure of ESG with the median value of ESG performance. As shown in Model (1), the coefficient of DT remains positive and statistically significant at the 1% level ($\beta = 0.0950$), indicating that the positive relationship between DT and ESG is not affected by the measurement of ESG performance.

Second, this study employs an alternative measure of DT to alleviate concerns regarding measurement bias. Specifically, following existing literature, DT is measured based on the proportion of digital-related intangible assets disclosed in firms' annual financial report notes relative to total intangible assets. When intangible asset items contain keywords related to digital technologies, such as software, network, client, management system, and intelligent platform, as well as related patents, these items are identified as digital technology-related intangible assets. The sum of these digital-related intangible assets is then divided by total intangible assets to construct an alternative proxy for DT. To ensure the accuracy of classification, manual verification is conducted for the identified digital-related intangible assets. The regression results in Model (2) show that the coefficient of the alternative DT measure remains significantly positive ($\beta = 0.0448$, $p < 0.01$), confirming the robustness of the baseline findings.

Third, this study adjusts the sample period by excluding observations after 2020 and re-estimates the baseline model. As reported in Model (3), the coefficient of DT remains positive and statistically significant at the 1% level ($\beta = 0.0682$), suggesting that the main findings are not driven by changes in the sample period.

Overall, the robustness tests consistently demonstrate that DT has a significant positive impact on ESG. The results remain stable after changing the measurement of ESG, adopting an alternative DT indicator, and adjusting the sample period, further supporting the validity of the baseline conclusion.

Table 3. Robustness Tests.

	(1)	(2)	(3)
	ESG_mid	ESG	ESG
DT	0.0950*** (8.731)		0.0682*** (4.916)
DT_2		0.0448*** (4.240)	
Growth	-0.0003* (-1.965)	-0.0003* (-1.969)	-0.0007*** (-3.708)
Lev	-0.0071*** (-8.652)	-0.0068*** (-8.509)	-0.0066*** (-7.234)
Mown	0.0030*** (5.720)	0.0027*** (5.009)	0.0037*** (4.793)
DirectorNumber	0.1624*** (28.030)	0.1641*** (28.076)	0.1535*** (20.389)

IND	0.0472*** (49.589)	0.0479*** (51.682)	0.0497*** (37.802)
Dual	-0.0367** (-2.396)	-0.0305* (-1.948)	-0.0817*** (-3.305)
TO10	0.0056*** (7.043)	0.0049*** (6.293)	0.0046*** (4.841)
Constant	0.6397*** (10.417)	0.6956*** (11.530)	0.6862*** (7.766)
N	49,996	49,996	27,266
R-squared	0.212	0.218	0.220
Industry	YES	YES	YES
Year	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

4.4. Mechanism Analysis

To further investigate the mechanisms underlying the impact of DT on ESG, this study examines the mediating effects of ICQ and KZ. Specifically, this study explores whether DT enhances ESG performance by improving ICQ and alleviating financing constraints. The results are presented in Table 4.

First, this study examines the mediating role of ICQ. Model (1) reports the direct effect of DT on ESG, where the coefficient of DT is significantly positive ($\beta = 0.0923$, $p < 0.01$), confirming the baseline relationship. Model (2) examines the effect of DT on ICQ, and the coefficient of DT is significantly positive ($\beta = 0.1401$, $p < 0.01$), indicating that DT significantly improves firms' ICQ. After incorporating ICQ into the ESG regression model, Model (3) shows that ICQ has a significantly positive effect on ESG ($\beta = 0.1438$, $p < 0.01$), while the coefficient of DT remains positive and significant ($\beta = 0.0721$, $p < 0.01$). These results suggest that ICQ partially mediates the relationship between DT and ESG, indicating that DT promotes ESG performance by strengthening internal governance and control capabilities.

Second, this study examines the mediating effect of KZ. Model (4) investigates the relationship between DT and KZ, and the coefficient of DT is significantly negative ($\beta = -0.0085$, $p < 0.01$), suggesting that DT effectively alleviates firms' financing constraints. Model (5) introduces KZ into the ESG regression model. The coefficient of KZ is significantly positive ($\beta = 1.0663$, $p < 0.01$), while the coefficient of DT remains significantly positive ($\beta = 0.0832$, $p < 0.01$). Considering that a higher KZ value represents lower financing constraints after the index adjustment, these results indicate that financing capability serves as an important transmission channel through which DT enhances ESG performance.

Overall, the mechanism analysis demonstrates that DT improves ESG performance through two channels: strengthening internal control quality and alleviating financing constraints. These findings provide further support for Hypotheses 2 and 3.

Table 4. Mechanism Analysis.

	(1)	(2)	(3)	(4)	(5)
	ESG	ICQ	ESG	KZ	ESG
DT	0.0923*** (8.568)	0.1401*** (7.055)	0.0721*** (7.783)	-0.0085*** (-4.712)	0.0832*** (8.289)
ICQ			0.1438*** (39.502)		
KZ					-1.0663*** (-26.413)
Growth	-0.0003** (-2.311)	0.0041*** (4.882)	-0.0009*** (-7.291)	-0.0000 (-0.603)	-0.0003*** (-2.791)
Lev	-0.0069*** (-8.683)	-0.0074*** (-5.473)	-0.0059*** (-8.241)	-0.0022*** (-16.209)	-0.0092*** (-12.315)

Mown	0.0031***	-0.0026***	0.0034***	0.0005***	0.0036***
	(5.852)	(-3.007)	(7.230)	(7.651)	(7.238)
DirectorNumber	0.1611***	0.2157***	0.1301***	-0.0183***	0.1416***
	(28.221)	(34.130)	(24.069)	(-27.600)	(25.927)
IND	0.0474***	0.0582***	0.0390***	-0.0051***	0.0419***
	(50.712)	(32.650)	(45.602)	(-30.065)	(47.710)
Dual	-0.0350**	-0.1300***	-0.0163	0.0137***	-0.0204
	(-2.310)	(-4.861)	(-1.101)	(4.259)	(-1.336)
TO10	0.0054***	-0.0139***	0.0074***	0.0024***	0.0079***
	(6.975)	(-6.090)	(12.804)	(12.156)	(12.474)
Constant	0.6592***	2.5588***	0.2913***	-0.1994***	0.4466***
	(10.998)	(16.372)	(5.164)	(-13.578)	(7.588)
N	49,996	49,996	49,996	49,996	49,996
R-squared	0.221	0.129	0.290	0.199	0.255
Industry	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

4.5. Heterogeneity Analysis

The baseline regression results confirm the positive effect of DT on ESG. However, the economic consequences of DT may vary depending on firms' institutional characteristics and external operating environments. Therefore, this study further conducts heterogeneity analyses from two perspectives: ownership structure and industry pollution characteristics. The regression results are reported in Table 5.

Table 5. Heterogeneity Analysis.

	(1)	(2)	(3)	(4)
	ESG	ESG	ESG	ESG
DT	0.1077***	0.0929***	0.0892***	0.1009***
	(7.409)	(6.911)	(7.444)	(4.609)
Growth	-0.0007***	0.0000	-0.0004**	-0.0002
	(-3.375)	(0.160)	(-2.120)	(-1.021)
Lev	-0.0042***	-0.0083***	-0.0075***	-0.0058***
	(-4.783)	(-10.288)	(-8.544)	(-3.751)
Mown	-0.0092***	0.0051***	0.0031***	0.0026***
	(-2.651)	(9.736)	(4.916)	(2.723)
DirectorNumber	0.0549***	0.1711***	0.1663***	0.1519***
	(4.113)	(32.993)	(23.947)	(16.532)
IND	0.0230***	0.0481***	0.0453***	0.0518***
	(8.656)	(49.554)	(38.830)	(33.273)
Dual	-0.0102	0.0027	-0.0397**	-0.0238
	(-0.244)	(0.191)	(-2.261)	(-0.708)
TO10	0.0080***	0.0039***	0.0056***	0.0048***
	(7.211)	(3.954)	(7.319)	(2.688)
Constant	2.3828***	0.5641***	0.6836***	0.5851***
	(11.982)	(7.507)	(10.940)	(4.560)
N	15,768	34,227	33,993	16,003
R-squared	0.129	0.281	0.207	0.250
Industry	YES	YES	YES	YES
Year	YES	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

First, this study examines the heterogeneity of the DT–ESG relationship across firms with different ownership structures. Models (1) and (2) present the regression results for SOEs and non-SOEs,

respectively. The results indicate that the coefficients of DT are significantly positive in both subsamples, suggesting that DT consistently contributes to improving ESG performance regardless of ownership type. However, the estimated coefficient of DT is larger in SOEs (0.1077) than in non-SOEs (0.0929), implying that the ESG-enhancing effect of DT is relatively stronger among SOEs. A possible explanation is that SOEs generally possess advantages in terms of resource accessibility, policy support, and governance systems, which may facilitate the integration of digital technologies with sustainable development practices and enhance the effectiveness of digital transformation in promoting ESG performance. Second, this study investigates whether the effect of DT on ESG differs between pollution-intensive and non-pollution-intensive industries. Models (3) and (4) report the corresponding results. The findings show that DT has a significantly positive impact on ESG in both groups, demonstrating the general applicability of the digital transformation effect. Furthermore, the coefficient of DT is slightly higher in non-pollution-intensive industries (0.1009) compared with pollution-intensive industries (0.0892). This difference may arise because firms in pollution-intensive industries are subject to stronger environmental constraints and face greater adjustment costs associated with green transformation, which may partially offset the marginal benefits generated by DT. In contrast, non-pollution-intensive firms may more efficiently utilize digital technologies to improve information transparency, optimize governance processes, and enhance sustainable development capabilities.

Overall, the heterogeneity analysis suggests that the positive relationship between DT and ESG is robust across different ownership structures and industry characteristics, while the magnitude of the effect varies depending on firms' resource endowments and external institutional pressures.

5. Conclusion

This study investigates the impact of DT on corporate ESG performance and further explores the underlying mechanisms through which DT affects ESG. Using a panel dataset of Chinese A-share listed firms from 2010 to 2023, this study constructs a two-way fixed effects model to examine the relationship between DT and ESG. The empirical results demonstrate that DT significantly improves corporate ESG performance. The findings remain robust after conducting a series of robustness checks, including replacing the measurement of ESG, adopting an alternative measure of DT, and adjusting the sample period.

Furthermore, the mechanism analysis reveals that DT enhances ESG performance through two important channels. First, DT significantly improves ICQ, thereby strengthening internal governance capabilities and promoting firms' sustainable development practices. Second, DT alleviates financing constraints, providing firms with greater resource support for long-term ESG-related investments. These findings highlight the internal governance and resource allocation mechanisms through which digital transformation contributes to corporate sustainability.

The heterogeneity analysis further indicates that the impact of DT on ESG varies across different institutional and industrial contexts. Specifically, the positive effect of DT on ESG is more pronounced among SOEs compared with non-SOEs, reflecting the role of resource advantages and institutional support in facilitating the transformation of digital capabilities into sustainable development outcomes. In addition, the ESG-enhancing effect of DT exists in both pollution-intensive and non-pollution-intensive industries, while the effect is relatively stronger among non-pollution-intensive firms.

This study contributes to existing literature in several ways. First, it extends research on the economic consequences of digital transformation by linking DT with corporate ESG performance and revealing its role in promoting sustainable development. Second, this study enriches the understanding of the mechanisms underlying the DT–ESG relationship by identifying the mediating roles of internal control quality and financing constraints. Third, by examining heterogeneous effects across ownership structures and industry characteristics, this study provides a more nuanced

understanding of how digital transformation generates sustainability benefits under different institutional environments.

The findings also provide practical implications. For policymakers, promoting digital infrastructure development and encouraging firms to accelerate digital transformation can serve as important pathways for achieving sustainable economic development. For enterprises, digital transformation should not be viewed merely as a technological upgrading strategy but as a comprehensive governance transformation that can improve internal management efficiency, optimize resource allocation, and enhance ESG performance. Therefore, firms should strengthen the integration of digital technologies with sustainability strategies to achieve long-term value creation.

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