Digital Transformation and Corporate ESG Performance: Nonlinear Dynamics, Heterogeneous Effects, and Threshold Mechanisms

Meng Liu[1*], Linxin Guo[2], Tingqiang Chen[1]

[1]School of Economics and Management, Nanjing Tec University, Nanjing 211816, Jiangsu, China
[2]School of Economics and Management, Chinese Academy of Sciences University, Beijing 100086, China

*15850765259@163.com

Abstract. Existing evidence on its relationship with ESG performance remains fragmented and contradictory. This ambiguity stems from three unresolved challenges: the potential nonlinearity of the effect, the differential responses across ESG sub-dimensions (Environmental, Social, and Governance), and the conditional nature of the gains depending on firm-specific endowments. To address these, this study utilizes data from Chinese A-share listed firms and applies quadratic and threshold regression models. The findings reveal a U-shaped nonlinear enhancement of overall ESG scores, driven by accelerating improvements in E and S dimensions, while governance scores decline linearly due to transition costs and institutional inertia. The effects are heterogeneous across firm types, regions, pollution intensity, and ownership, and are conditioned by profitability thresholds. This study reconciles prior conflicting evidence and provides policy insights for optimizing ESG outcomes through targeted digital strategies.

Keywords: Digital transformation; ESG; Technological innovation; Labor share

1 Introduction

ESG framework (Environmental, Social, and Governance criteria) have become central to encouraging corporate social responsibility and integrating sustainability into operational evaluations (Gillan et al., 2021). China has pursued a "top-down" ESG development approach spearheaded by multiple regulatory bodies. By September 2024, over 20% of central SOEs had incorporated ESG into brand development, with disclosure rates approaching 99.5%.

Economically, ESG frameworks internalize corporate externalities into operational costs. Building upon the framework of the UN Sustainable Development Goals (Dechow, 2023), this approach enables firms to proactively pursue sustainable devel-

© The Author(s) 2026
V. Erokhin et al. (eds.), *Proceedings of the 6th International Conference on Internet Finance and Digital Economy (ICIFDE 2026)*, Advances in Economics, Business and Management Research 412,
https://doi.org/10.2991/978-94-6239-830-6_27

opment. The 2030 Agenda further highlights digital technology's role in green sustainable development. Currently, there is widespread interest in how digitalization impacts sustainability. Li et al. (2025) conducted a study on this topic and explored the mechanisms from various perspectives. However, the findings are not consistent, which underscores the need for further investigation into the underlying mechanisms through which digital transformation exerts its influence.

Contemporary research links digital transformation to corporate ESG performance through digital technology empowerment, innovative element structure optimization and management efficiency enhancement. First, digital transformation has expanded the extent to which enterprises are leveraging AI and IOT. This enhancing their innovation capabilities (Huang et al., 2024). Furthermore, this also creates economies of scale, which is highly advantageous for enterprises engaged in sustainable development, as they can leverage more resources. Second, dgital transformation has enhanced the efficiency of resource allocation, including both capital and human resources. This, in turn, has improved the income distribution structure and ultimately fostered social equity (Yu, 2024). Lu et al. (2024) identify a "skill-oriented" labor structure optimization that reduces routine position demand. Third, The improved management efficiency resulting from transformation has helped reduce unnecessary expenditures, creating self-reinforcing cycles that redirect spending toward technological innovation (Lou and Hu, 2024).

While previous analyses often focused on linear relationships, it is also important to note that implementing digital transformation requires significant upfront investment, and the benefits typically materialize with a time lag, which can be detrimental to ESG performance. But, once transformation is successfully completed (usually when a certain threshold is reached), the resulting benefits often become substantial, such as economies of scale. At this point, their impact is positive and significant. It is appropriate to focus on the threshold characteristic and the U-shaped dynamic relationship. Accordingly, we propose:

H1: ESG performance is subject to the non-linear impact of digital transformation.

The negative externalities of pollution and the waste of resources are long-standing issues that are difficult to address using traditional approaches. However, digital transformation can help overcome the limitations of conventional governance methods across multiple stages, such as monitoring, decision-making, and intervention, thereby achieving a Pareto improvemen through systemic restructuring and data-driven decision-making (Ning et al., 2023). For social performance, digital transformation leverages scalability and replicability to create incremental social value while systematically displacing established CSR models, ultimately catalyzing novel responsibility paradigms. Furthermore, governance-related challenges, such as low decision-making efficiency, information asymmetry, and high transaction costs, are gradually being mitigated through the application of digital technologies. Thus:

H2a: Environmental performance (E) is subject to the non-linear impact of digital transformation.

H2b: Social responsibility performance (S) is subject to the non-linear impact of digital transformation.

H2c: Governance performance (G) is subject to the non-linear impact of digital transformation.

The innovative facilitation effect is constrained by endowment size thresholds (different types of enterprises), reflecting non-linear marginal returns under resource limitations. Consequently:

H3: The effectiveness of digital transformation varies across different types of enterprises, reflecting heterogeneous differences; meanwhile, economies of scale serve as a moderating factor on this effectiveness.

Compared to previous studies, the innovation of this paper lies in the development of a comprehensive research framework. Within this analytical framework, we place greater emphasis on the nonlinear impact of digital transformation on ESG performance, the role of corporate heterogeneity, and the underlying mechanisms. Additionally, the moderating effect of economies of scale has been incorporated into the analysis. Our study serves to reconcile the conflicting empirical findings in the academic literature and represents a valuable supplement.

Using panel data from 1,531 Chinese listed companies (2012–2023), we employ quadratic regression to capture nonlinear dynamics and threshold regression to identify the profitability threshold conditioning digital transformation's ESG efficacy. Furthermore, mediation analysis is conducted to examine the underlying channels. Through comprehensive heterogeneity analysis stratified by firm type (labor-, capital-, and technology-intensive), geographic region (eastern, central, and western), pollution intensity, factor margin, and ownership structure, we identify contextual heterogeneities.

2 Research Design

2.1 Data

We selected a sample of Chinese A-share listed companies. We obtained the relevant data from multiple databases, including the Wind Economic Database (WIND), the China Stock Market & Accounting Research Database (CSMAR), the China Research Data Services Platform (CNRDS). In total, we have 18,372 observations covering 1,531 enterprises over the period from 2012-2023. For missing data, we supplemented them using the companies' official annual reports. Firms are classified by industry according to the China Listed Companies Association's quarterly revisions, excluding financial institutions (banks, securities, and insurance). We performed partial deletion on the original sample; the deleted observations included enterprises labeled as ST, *ST or PT, enterprises with severe missing observations, and enterprises that were delisted during the sample period. All continuous variables are winsorized at the 1st and 99th percentiles; isolated missing values (notably in 2022) are imputed using the Gray Forecasting Model.

2.2 Model

We estimate the following baseline models to test the effects of digital transformation:

$$ESG_{j,t} = \alpha_0^1 + \alpha_1^1 DIG_{j,t} + \sum \alpha_i^1 Z_{j,t} + \gamma_j^1 + \mu_t^1 + \varepsilon_{j,t}^1 \quad (1)$$

$$ESG_{j,t} = \alpha_0^2 + \alpha_1^2 DIG_{j,t} + \alpha_2^2 DIG_{j,t}{}^2 + \sum \alpha_i^2 Z_{j,t} + \gamma_j^2 + \mu_t^2 + \varepsilon_{j,t}^2 \quad (2)$$

Where $ESG_{j,t}$ is the overall ESG disclosure quality, $DIG_{j,t}$ denotes digital transformation intensity, and $Z_{j,t}$ is a vector of control variables (Tobin's Q, equity concentration, independent director ratio, leverage, and revenue growth). Firm fixed effects (γ_j) and year fixed effects (μ_t) are included. The same specification is applied to the three sub-dimensions (E, S, G) by replacing the dependent variable.

To examine underlying mechanisms, we specify the following mediating effect models, Eq (3) and Eq (4)). Where the mediating variables are $TI_{j,t}$ (green technology innovation), $LS_{j,t}$ (labor income share), and $Mf_{j,t}$ (management expense efficiency).

$$TI_{j,t}(LS_{j,t}; Mf_{j,t}) = \beta_0^1 + \beta_1^1 DIG_{j,t} + \sum \beta_i^1 Z_{j,t} + \theta_j^1 + \eta_t^1 + \xi_{j,t}^1 \quad (3)$$

$$TI_{j,t}(LS_{j,t}; Mf_{j,t}) = \beta_0^2 + \beta_1^2 DIG_{j,t} + \beta_2^2 DIG_{j,t}{}^2 + \sum \beta_i^2 Z_{j,t} + \theta_j^2 + \eta_t^2 + \xi_{j,t}^2 \quad (4)$$

For the threshold regression model, we use $TP_{j,t}$ (Total Profit) as the threshold variable. The specific specification is given by Eq (5).

$$ESG_{j,t} = \alpha_0^3 + \sum \alpha_i^3 Z_{j,t} + \gamma_j^3 + \mu_t^3 + \varepsilon_{j,t}^3 + \begin{cases} \alpha_1^3 DIG_{j,t} & TP_{j,t} \le TP^* \\ \alpha_1^{3*} DIG_{j,t} & TP_{j,t} > TP^* \end{cases} \quad (5)$$

2.3 Variable Definitions and Measurement

Key variables are constructed as follows.

Dependent variable: *ESG* disclosure quality is measured by the Huazheng ESG Comprehensive Scoring System, which provides continuous scores for overall ESG and separate sub-scores for *E*, *S*, and *G*.

Independent variable: *DIG* is constructed using text mining of annual reports, based on a lexicon of 99 keywords across four dimensions. For robustness, an alternative measure using 76 keywords from Liu et al. (2024) is employed.

Mechanism and threshold variables: *TI* is measured by green total factor productivity computed via DEA with R&D, fixed assets, and employee compensation as inputs, and green patents and net profit as outputs. *LS* follows the factor-cost approach. *Mf* is operating revenue divided by management expenses. *TP* is pre-tax profit.

Table 1. Variable definitions.

Variable	Symbol	Measurement
ESG overall score	ESG	Continuous Huazheng ESG composite score
Environmental score	E	Huazheng sub-score for environmental performance

Social score	S	Huazheng sub-score for social responsibility
Governance score	G	Huazheng sub-score for corporate governance
Digital transformation	DIG	ln(1 + total frequency of 99 digital-related keywords in annual reports)
Green technological innovation	TI	Green total factor productivity from DEA (inputs: R&D, fixed assets, labor; outputs: green patents, net profit)
Labor income share	LS	(Employee cash compensation + employer social contributions) / (Operating surplus + employee compensation + depreciation)
Management expense efficiency	Mf	Operating revenue / Management expenses
Total profit	TP	Pre-tax profit (threshold variable)
Leverage	Lev	Total liabilities / Total assets
Equity concentration	Top	Shareholding percentage of the top five shareholders
Independent director ratio	Indep	Number of independent directors / Total board members
Tobin's Q	TobinQ	Market value / Replacement cost of assets
Revenue growth	Growth	Year-on-year growth rate of operating revenue

Control variables: include leverage (*Lev*), equity concentration (*Top*), proportion of independent directors (*Indep*), Tobin's Q (*TobinQ*), and revenue growth (*Growth*). Detailed definitions are provided in Table 1.

3 Empirical Results

3.1 Baseline Regression Results

Table 2 reports the fixed-effects estimates of Eq(1) and Eq(2). *DIG* exhibits a significantly positive linear effect on the overall ESG score, and the quadratic term is also positive and significant, confirming a U-shaped relationship. Disaggregating into subdimensions reveals that environmental (*E*) and social (*S*) scores follow the same nonlinear accelerating pattern, whereas governance (*G*) scores show a significant negative linear association with DIG and no non-linearity. These results support H1: digital transformation enhances aggregate ESG through scale economies, primarily driven by

improvements in E and S, while G performance temporarily deteriorates due to transition costs and institutional inertia.

Table 2. Baseline regression results.

	ESG score			E-Score	S-Score	G-Score
	(1)	(2)	(3)	(4)	(5)	(6)
DIG	0.3213***	0.3540***	-0.1525	0.5730***	1.4304***	-0.7990***
	(0.0376)	(0.0374)	(0.1102)	(0.1580)	(0.2109)	(0.1625)
DIG^2	—	—	0.0968***	0.1182***	0.1106***	0.0146
			(0.0199)	(0.0284)	(0.0379)	(0.0292)
Cons	71.8719***	69.4170***	69.9226***	61.9346***	66.2740***	75.3599***
	(0.1144)	(0.4665)	(0.4775)	(0.6846)	(0.9135)	(0.7039)
OBS	18,372	18,372	18,372	18,372	18,372	18,372
Time/Pro/Ind/*Control*	YES	YES	YES	YES	YES	YES
F	11.24***	10.25***	10.28***	11.05***	9.36***	6.61***

Notes： *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Time, Pro, and Ind represent time, province, and industry fixed effects. Control denotes the inclusion of control variables.

3.2 Heterogeneity Analysis

We examine heterogeneity by firm type, region, pollution intensity, factor intensity, and ownership (Sun et al., 2024).

For capital-intensive firms, digital transformation exerts the strongest positive driving force. Capital-intensive firms exhibit the strongest non-linear acceleration, technology-intensive firms show a delayed but significant U-shaped effect, and labour-intensive firms display a linear positive relationship. Regionally, eastern firms enjoy the most pronounced acceleration, central firms show transitional patterns, and western firms experience mainly linear improvements. These patterns reflect differential digital infrastructure and institutional complementarities. These results are reported in Table 3.

Table 3. Heterogeneity regression.

	ESG					
	(1) labor-intensive	(2) capital-intensive	(3) technology-intensive	(4) eastern region	(5) central region	(6) western region
DIG(1)	0.2770***	0.4977***	0.1251	0.3497***	0.4082***	0.3032***
	(0.0671)	(0.0605)	(0.0834)	(0.0471)	(0.0829)	(0.0936)
DIG(2)	0.1877	-0.1197	-0.3397	-0.2458*	-0.0650	-0.1115
	(0.1982)	(0.1751)	(0.2550)	(0.1398)	(0.2469)	(0.2931)
DIG^2	0.0176	0.1106***	0.1012**	0.1088***	0.0989**	0.0855
	(0.0367)	(0.0294)	(0.0525)	(0.0240)	(0.0486)	(0.0573)
Time/Pro/Ind/*Control*	YES	YES	YES	YES	YES	YES
OBS	6758	7588	3749	11951	3470	2951

Notes: See the Appendix for comprehensive classification criteria. *DIG(1)* in models excluding its quadratic term. *DIG(2)* in models including both linear and quadratic terms.

For environmental performance, digital transformation raises E-scores in both high- and low-pollution firms, but only low-pollution firms exhibit significant non-linear acceleration. For social performance, technology-margin firms show stronger positive and accelerating effects on S-scores than labour-margin firms. For governance, the negative impact on G-scores is significantly larger for state-owned enterprises than for non-SOEs. These results are reported in Table 4. These findings confirm H3.

Table 4. Heterogeneity regression for E, S, and G.

	E		S		G	
	(1) high-pollution	(2) low-pollution	(3) technical margin	(4) labor margin	(5) state-owned	(6) non-state-owned
DIG(1)	1.1931*** (0.0977)	1.1874*** (0.0666)	2.3734*** (0.0903)	1.5340*** (0.1232)	-0.8757*** (0.0729)	-0.5443*** (0.0834)
DIG(2)	0.9781*** (0.2951)	0.3109 (0.1583)	1.8029*** (0.2561)	0.9011** (0.3842)	-0.7271*** (0.2153)	-0.7351*** (0.2487)
DIG^2	0.0480 (0.0622)	1.1874*** (0.0666)	0.1059** (0.0445)	0.1026 (0.0729)	-0.8300 (0.0409)	0.0346 (0.0425)
Time/Pro/Ind/*Control*	YES	YES	YES	YES	YES	YES
OBS	4941	13431	10670	7702	9408	8964

Notes: Comprehensive classification details are provided in the Appendix.

3.3 Mechanism Analysis

Using Eq (3) and Eq(4), we test the mediating roles of *TI*, *LS*, and *Mf*. Results are reported in Table 5.

First, *DIG* significantly promotes *TI*, with a positive quadratic term. Since green innovation is a key pathway for corporate green transition (Yang & Chi, 2023), this confirms that digitalisation accelerates green innovation and thus raises E-scores (H2a).

Second, *DIG* has a U-shaped effect on *LS*, it initially decreases and then increases labour income share, reflecting the substitution of routine labour followed by skill-premium effects. This dynamic explains the phased improvement in S-scores (H2b).

Third, *DIG* linearly reduces *Mf* (management expense efficiency), with an insignificant quadratic term, indicating that most firms remain in the cost-increasing phase of digital governance transformation, which depresses G-scores (H2c).

Table 5. Mechanism.

	TI		LS		Mf	
	(1)	(2)	(3)	(4)	(5)	(6)
DIG	0.0960*** (0.0024)	0.0382*** (0.0070)	-0.0003*** (0.0000)	0.0017*** (0.0001)	-0.0210*** (0.0040)	-0.1303*** (0.0117)
DIG^2	—	0.0111*** (0.0013)	—	-0.0004*** (0.0000)	—	0.0209*** (0.0021)
Time/Pro/Ind/*Control*	YES	YES	YES	YES	YES	YES
OBS	18,372	18,372	18,372	18,372	18,372	18,372

Notes: Classification criteria align with Table 2.

3.4 Threshold Effects

To further validate the non-linear and stage-dependent nature, we estimate threshold regressions based Eq(5).

Using total profit (*TP*) as the threshold, the positive effect of *DIG* on ESG is substantially weaker below the profit threshold than above it. This confirms that adequate profitability is the financial foundation for realising ESG gains from digitalization. The relevant results are shown in Table 6.

Table 6. Digital transformation raises the threshold for corporate ESG performance.

	ESG		ESG		ESG	
	(1) lower	(2) upper	(3) lower	(4) upper	(5) lower	(6) upper
DIG	0.1626*** (0.0405)	0.4758*** (0.0403)	0.2045*** (0.0403)	0.4943*** (0.0400)	—	
inDIG	—		—		0.1905*** (0.0382)	0.4822*** (0.0384)
Threshold (*TP*)	5.4460*** (4.7640; 5.5250)		5.4460*** (4.6940; 5.5250)		5.4460*** (4.6940; 5.5250)	
Time/Pro/Ind/*Control*	YES		YES		YES	
OBS	13310	5062	13310	5062	13310	5062

Notes: Classification criteria align with Table 2. Threshold denotes the threshold variable and its value range. Estimation employs 300 bootstrap iterations at 95% confidence.

4 Conclusion

As corporate ESG performance is a key driver of sustainable development, it is crucial to investigate the role of digital transformation on this performance. We empirically test this proposition using data from China.The results show a U-shaped nonlinear enhancement of overall ESG scores, primarily driven by accelerated gains in environmental (E) and social (S) dimensions, whereas governance (G) scores decline linearly due to transition costs and institutional inertia. The effects are heterogeneous across firm types, regions, pollution intensity, and ownership, and are conditioned by profitability thresholds. This study contributes by integrating technological innovation, labour substitution/creation, and management efficiency mechanisms within a scale-economy framework, reconciling prior conflicting evidence. Limitations include the single-country sample and the short-term negative governance effect; future research should extend to cross-country settings and explore the co-evolution of ESG rating divergence and digital governance over longer windows.

Acknowledgment

Funding: This research was supported by National Social Science Fund Youth Project of China (grant No. 24CJL014) and Jiangsu Provincial Social Science Fund Youth Project of China (grant No. 23EYC01).

References

1. Dechow, P. M. (2023). Understanding the sustainability reporting landscape and research opportunities in accounting. The Accounting Review, 98(5), 481-493. https://doi.org/10.2308/TAR-2023-0145
2. Gillan, S. L., Koch, A., & Starks, L. T. (2021). Firms and social responsibility: A review of ESG and CSR research in corporate finance. Journal of Corporate Finance, 66, 101889. https://doi.org/10.1016/j.jcorpfin.2021.101889
3. Huang, X., Sun, Y., & Chen, M. (2024). Digital transformation and disruptive technovation: evidence from patent networks and the SBERT models. China Industrial Economics, (10), 137–154. https://doi.org/10.19581/j.cnki.ciejournal.2024.10.008
4. Li, P., Li, X., & Wu, Q. (2025). Digitalization drives Sustainability: How digital trade enhances corporate ESG performance through innovation, internationalization and transparency. International Review of Economics & Finance, 101, 104248. https://doi.org/10.1016/j.iref.2025.104248
5. Liu H, Zhu J, Cheng H (2024) Enterprise digital transformation's impact on stock liquidity: A corporate governance perspective. PLoS ONE 19(3): e0293818. https://doi.org/10.1371/journal.pone.0293818
6. Lu, S.,Peng, S., Shi, J., Zhang, C., & Feng, Y. (2024). How does digital transformation affect the total factor productivity of China's A-share listed enterprises in the mineral resource-based sector? Resources Policy, 94, 105146. https://doi.org/10.1016/j.resourpol.2024.105146.
7. Ning, J., Jiang, X., &Luo, J. (2023).Relationship between enterprise digitalization and green innovation: A mediated moderation mode. Journal of Innovation & Knowledge, 8(1),100326. https://doi.org/10.1016/j.jik.2023.100326
8. Sun, Y., Zhao, D., & Cao, Y. (2024). The impact of ESG performance, reporting framework, and reporting assurance on the tone of ESG disclosures: Evidence from Chinese listed firms. Journal of Cleaner Production, 466, 142698.https://doi.org/10.1016/j.jclepro.2024.142698
9. Yang, Y., & Chi, Y. (2023). Path selection for enterprises' green transition: Green innovation and green mergers and acquisitions. Journal of Cleaner Production, 412, 137397. https://doi.org/10.1016/j.jclepro.2023.137397
10. Yu, G. (2024). Digital transformation, human capital upgrading, and enterprise ESG performance: Evidence from Chinese listed enterprises. Oeconomia Copernicana.15(4), 1465-1508. https://doi.org/10.24136/oc.3058

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

