Received: 26 April 2023 | Revised: 13 September 2023 | Accepted: 20 October 2023

DOI: 10.1002/csr.2656

RESEARCH ARTICLE

Corporate Social Responsibility and Environmental Management

WILEY

The impact of digital transformation on ESG performance and the moderation of mixed-ownership reform: The evidence from Chinese state-owned enterprises

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Abstract

This article selects state-owned enterprises listed on the A-share market of China from 2010 to 2021 as the research sample, and adopts the Ordered Logistic Model to analyze the relationship between digital transformation (DX) and environment, social and governance (ESG) performance of enterprises, and studies the moderating effect of mixed-ownership reform. The study found that: the DX of state-owned enterprises can indeed improve ESG performance, and its time lag effect is significant; for state-owned enterprises located in high-tech industries, with higher level of marketization, or in the maturity stage, their DX has a significant promoting effect on ESG performance; In addition, mixed-ownership reform can amplify the positive impact of DX of state-owned enterprises on ESG performance.

KEYWORDS

digital transformation, ESG, mixed-ownership reform, state-owned enterprise

1 | INTRODUCTION

In recent years, global social stability and economic development have been threatened by climate change and energy crises, and seeking sustainable development solutions has become a consensus among countries worldwide. Against the backdrop of pursuing sustainable transformation and development, investors' attention to corporate green management capabilities and social responsibility has also been increasing. As a result, theories related to sustainable development and corporate social responsibility have emerged, which provide guidance for the sustainable development of enterprises.

Corporate Social Responsibility Theory holds that businesses are a collection of different stakeholders, and that businesses should fulfill their social responsibilities on at least four levels: economic, legal, ethical, and philanthropic (Carroll, 1991). In the daily process of production and operation, businesses should also pay attention to three bottom lines: profit, human capital, and the environment, to unify economic, social, and ecological benefits and achieve long-term sustainable development (Elkington, 1998). Sustainable Development Theory proposes the concept of inclusive development (Kunarto & Prasetyo, 2022), which seeks to achieve long-term economic stability and development, social justice and fairness, and ecological sustainability (UN DESA, 2016; Robinson et al., 2016). These two theories not only focus on business stakeholders' demands, but also embrace inclusive and intergenerational perspectives on long-term development, making the ESG concept an essential guiding principle for business operations today (Becchetti et al., 2018). A large body of research has shown that strong ESG performance by enterprises helps to gain trust and support from stakeholders (Deng et al., 2013; Edmans, 2011), which in turn can improve financial performance (Flammer, 2015), increase market value (Fatemi et al., 2018), reduce the cost of equity (Faysal et al., 2020a), ease financing constraints (Feng & Wu, 2023; Jiang, 2022), and improve financial performance (Salehi et al., 2018); moreover, some viewpoints believe that gaining a more "strapping" corporate reputation will also be achieved by more transparent ESG disclosure, which does benefits to minimizing the negative side effects (Brockett & Rezaee, 2012; Zimon et al., 2022).

However, it remains to be seen what factors influence an enterprise's ESG performance and how it could improve its ESG performance. With the digitalization trend, digital transformation (DX) has naturally become one of the focuses of scholars. Some viewpoints have suggested that digital technology has a profound impact on non-financial performance, such as ESG, as the inclusiveness and convenience of digital technology are conducive to corporate social responsibility and environmental governance practices (Adams & Frost, 2006; Li, 2023). DX can promote corporate social responsibility by reducing earnings management and promoting information disclosure (Koo et al., 2022).

In fact, in the context of a new round of industrial and technological revolution, developing the digital economy is an essential part of keeping up with the times. As the leading force of the state-owned economy, the state-owned economy should play a driving and guiding role in the new generation of information technology revolution. State-owned enterprises, as the backbone of the state-owned economy, naturally take the lead, and it has been proven that the DX of state-owned enterprises has become an essential engine for the high-quality development of the state-owned economy. Therefore, whether DX can help state-owned enterprises improve their environmental governance, social responsibility, and corporate management through ESG practices is an important issue under the background of the" carbon peaking and carbon neutrality goals" and the Digital Strategy of China. Moreover, what is even more pivotal is that the recent rise of the mixed-ownership reform has been highly anticipated. As a unique product of the public-ownership economy, the mixed-ownership reform is expected to ignite the vitality and creativity of enterprises, thereby making significant contributions to social responsibility and environmental governance. Therefore, it is also worth investigating whether mixed-ownership reforms can empower enterprises to enhance their ESG performance through DX.

On account of this, based on the data of listed state-owned enterprises in the A-share market of China from 2010 to 2021, this article empirically studies the impact of DX of state-owned enterprises on their ESG performance, and also tests the moderating effect of mixed-ownership reform on the relationship between DX and ESG performance.

2 | LITERATURE REVIEW AND RESEARCH HYPOTHESIS

2.1 | DX improves ESG performance

State-owned enterprises have unique characteristics, meaning they should play a leading role and set an example in fulfilling corporate social responsibility and emphasizing the environmental and social benefits of the enterprise (Stone et al., 2022). Currently, state-owned enterprises and state-owned asset regulatory agencies are gradually increasing their attention to ESG practices, and the State-owned Assets Supervision and Administration Commission and local governments have successively issued guidance on improving the ESG level and perfecting the ESG management system of state-owned enterprises (Sun et al., 2022). However, there are still some problems remain unsolved in the ESG practices of state-owned enterprises, including path dependence on the original development mode, inefficient resource utilization, and ineffective government regulation and social supervision (Sun et al., 2022; Zahid et al., 2023).

DX can provide new solutions for state-owned enterprises in ESG practices. Firstly, digital technology can have a revolutionary impact on enterprise business models, production methods, and organizational processes, enabling enterprise transformation and upgrading to move beyond traditional expansion models (Gaglio et al., 2022), which can promote the integration of innovative, green, and shared sustainable development concepts in the strategic transformation of state-owned enterprises. Secondly, enterprise DX reflects the transformation of enterprise management mode from "industrialization" to "digitalization" (Vetrova et al., 2023), which is conducive to reducing resource mismatches and improving enterprise resource allocation efficiency (Wielgos et al., 2021), and enhancing the level of green management of state-owned enterprises (Liu et al., 2022). In addition, digital technology can achieve interconnection and automation control of equipment, realize automated and intelligent production, reduce consumption of energy and generation of waste, and thus reduce the adverse impact on the environment (Llopis-Albert et al., 2021; Zhai et al., 2022). Moreover, the more effective resource allocation brought about by digital technology can enhance the green technology R&D level of state-owned enterprises (Tavoletti et al., 2022), and provide technical support for enterprise green management, which will be conducive to promoting governance performance (Ko et al., 2022; Wu & Li, 2023). Finally, DX can enhance enterprise information transparency, alleviate information asymmetry problems, which are usually generated by CEOs' showing opportunistic behaviors (Zimon et al., 2022); and then strengthen government regulation and social supervision effectiveness, and improve the social responsibility performance of state-owned enterprises (Koo et al., 2022). Thus, the following first hypothesis is tested:

Hypothesis 1. *Digital transformation of state-owned enterprisess can improve their ESG performance.*

2.2 | Mixed-ownership reform has positive moderating effects

Actually, there have been also some studies indicating that although digital technologies are able to ensure the effective achievement of sustainable development goals, considerable companies tend to use the benefits of DX focusing on maximizing short-term profits rather than taking into account the interests of future generations (Khattak & Yousaf, 2021; Vetrova et al., 2023). The emergence of the principal-agent problem matters, in which the root cause of the mixed-ownership reform lies.

The principal-agent theory in the 1930s held that the typical characteristic of modern corporations is the separation of ownership and management (Bernhold & Wiesweg, 2021). As social and economic development led to increasing specialization, limitations of time, energy, and abilities of the owners led to the delegation of significant responsibilities for business operations, giving rise to professional managers. However, the information asymmetry between shareholders as principals and managers as agents resulted in the principal-agent problem (Gong et al., 2017). Shareholders cannot fully understand the behavior and abilities of managers, who may take advantage of this information asymmetry to carry out opportunistic actions in their own interests (Maskin & Tirole, 1990; Salehi & Alkhyyoon, 2022) and establish managerial entrenchment on owners' actions (Zimon et al., 2022) in order to protect themselves against the risk of short-term tenure, finally resulting in the company's interests being damaged.

The core of the principal-agent problem in state-owned enterprises lies in their "ownership." There is no identifiable "ultimate principal" in the case of co-ownership (Yan et al., 2021). The state has nominal ownership in state-owned enterprises, while the business management or board of directors exercises the right to operate the enterprise. In such a situation, there are bound to be problems of information asymmetry, inadequate supervision, and distorted incentive mechanisms, which lead to the principal-agent problem (Xia & Zhou, 2022). The mixed-ownership reform introduces non-state capital into state-owned enterprises, changing the original ownership structure and management mode, and significantly reducing the probability of the principal-agent problem occurring. Mixed-ownership reform can constrain the behavior of the management or board of directors of state-owned enterprises (Liao et al., 2022; Yuan et al., 2022), making state-owned enterprises more focused on the long-term sustainable development of the company (Xia & Zhou, 2022); it also tends to adjust ownership structure and reduce the cost of equity, which will support the role of inside ownership in enhancing enterprises' performance (Faysal et al., 2020b). DX can thus further promote green innovation, enhance internal governance, and maximize the driving effect on ESG performance, under the background of mixed-ownership reform (Yuan et al., 2022). Thus, the following second hypothesis is tested:

Hypothesis 2. *Mixed-ownership reform positively moderates the relationship between digital transformation and ESG performance in state-owned enterprises.*

3 | MODEL AND VARIABLE SPECIFICATION

3.1 | Dependent and core independent variables

The dependent variable of this article is ESG performance (ESG), which is directly measured using the Chindices ESG ratings. The Chindices ESG ratings divide listed companies into eight levels (AA, A, BBB, BB, B, CCC, CC, C), possessing the characteristics of an ordered categorical variable.

The core independent variable of this article is digital transformation (DX). It is generally believed that DX achieves improved risk identification, discovery of opportunities, and internal control through digital technology, ultimately enhancing corporate competitiveness and value (Gilch & Sieweke, 2021), or promoting social change and comprehensive improvement (Majchrzak et al., 2016). Referring to Qi et al. (2022) and Li (2022), this article uses Python to logarithmically process the word frequency of "keywords" related to DX (including "digital technology application," "internet business model," "intelligent manufacturing" and "modern information system") in the annual reports of listed companies, in order to characterize the degree of DX of each state-owned enterprise.

3.2 | Econometric model

Based on the characteristic of the dependent variable as an ordered categorical variable, this article adopts the Ordered Logistic Model. First, considering an ordered probability model, which can be constructed by latent variable y_i^*:

$$y_i^* = \boldsymbol{\beta} \mathbf{x}_i' + \varepsilon_i (i = 1,2,\dots,n). \tag{1}$$

Then, the piecewise function of the ordered probability model, whose dependent variable is y, can be constructed via y_i^*:

$$y_i = \begin{cases} 1, & y_i^* \le r_1 \\ 2, & r_1 \le y_i^* \le r_2 \\ K, & r_K \le y_i^* \end{cases}. \tag{2}$$

Let $y_i^* = \alpha + \sum_{j=1}^{J} \beta_j x_{ij} + \varepsilon_i (i = 1,2,\dots,n)$, then for $\forall k$, multivariable ordered probability model $P(y_i \le k|x)$ can be expressed as:

$$P(y_i \le k|\mathbf{x}) = F\left(r_k - \left(\alpha + \sum_{j=1}^{J} \beta_j x_{ij}\right)\right). \tag{3}$$

While $\varepsilon_i \sim \text{Logistic}(\mu, s)$, Equation (3) can be expressed as:

$$\ln\left[\frac{P(y_i \le k|\mathbf{x})}{1 - P(y_i \le k|\mathbf{x})}\right] = \alpha_k - \sum_{j=1}^{J} \beta_j x_{ij}. \tag{4}$$

Equation (4) namely the Ordered Logistic Model. And for or specific $y_i = k$:

$$\begin{aligned} P(y_i = k|\mathbf{x}) &= P(y_i = k|\mathbf{x}) - P(y_i = k-1|\mathbf{x}) \\ &= \frac{e^{r_k - \left(\alpha + \sum_{j=1}^{J} \beta_j x_{ij}\right)}}{1 + e^{r_k - \left(\alpha + \sum_{j=1}^{J} \beta_j x_{ij}\right)}} - \frac{e^{r_{k-1} - \left(\alpha + \sum_{j=1}^{J} \beta_j x_{ij}\right)}}{1 + e^{r_{k-1} - \left(\alpha + \sum_{j=1}^{J} \beta_j x_{ij}\right)}}. \end{aligned} \tag{5}$$

Let $y_{ik} = \begin{cases} 1, i \in k \\ 0, i \notin k \end{cases}$, the probability mass function of joint probability distribution of Equation (5) can be expressed as:

$$\text{PMF} = \prod_{i=1}^{n} \prod_{k=1}^{K} P(y_{ik} = k|\mathbf{x})^{y_{ik}}. \tag{6}$$

With its log-likelihood function:

$$\begin{aligned}\ln L(\boldsymbol{\theta},\boldsymbol{x}) &= \ln\left[\prod_{i=1}^{n}\prod_{k=1}^{K}P(y_{ik}=k|\boldsymbol{x})^{y_{ik}}\right] = \sum_{i=1}^{n}\sum_{k=1}^{K}\ln\left[P(y_{ik}=k|\boldsymbol{x})^{y_{ik}}\right] \\ &= \sum_{i=1}^{n}\sum_{k=1}^{K}y_{ik}\ln\left[\frac{e^{\alpha_k-\sum_{j=1}^{J}\beta_j x_{ij}}}{1+e^{\alpha_k-\sum_{j=1}^{J}\beta_j x_{ij}}}-\frac{e^{\alpha_{k-1}-\sum_{j=1}^{J}\beta_j x_{ij}}}{1+e^{\alpha_{k-1}-\sum_{j=1}^{J}\beta_j x_{ij}}}\right].\end{aligned} \tag{7}$$

The estimation for parameter $\boldsymbol{\theta}(\boldsymbol{\alpha},\boldsymbol{\beta})$ can be realized by conducting the partial derivative of Equation (7) with respect to $\boldsymbol{\theta}(\boldsymbol{\alpha},\boldsymbol{\beta})$:

$$\begin{cases}\dfrac{\partial \ln L(\boldsymbol{\theta},\boldsymbol{x})}{\partial \alpha_k}=\displaystyle\sum_{i=1}^{n}\left[y_{ik}\frac{P_{ik}(1-P_{ik})}{P_{ik}-P_{i,k-1}}-y_{i,k+1}\frac{P_{ik}(1-P_{ik})}{P_{i,k+1}-P_{i,k}}\right] \\ \dfrac{\partial \ln L(\boldsymbol{\theta},\boldsymbol{x})}{\partial \beta_i}=-\displaystyle\sum_{i=1}^{n}\sum_{k=1}^{K}y_{ik}y_{ij}\left[1-P_{ik}-P_{i,k-1}\right]\end{cases}. \tag{8}$$

Equation (8), namely the non-linear equations of $\boldsymbol{\theta}(\boldsymbol{\alpha},\boldsymbol{\beta})$, which can be solved through Gradient Descent.

3.3 | Control variables specification

Based on the characteristic of the dependent variable as an ordered categorical variable, this article adopts the Ordered Logistic Model. First, considering an ordered probability model, which can be constructed by latent variable y_i^*: referring to He et al. (2022), Zhai et al. (2022), and Zhou et al. (2022), this article selects variables that may have an impact on DX and ESG performance of an enterprise, at the level of accounting, equity structure, and corporate governance, including "enterprise size (asset)," "enterprise age (age)," "debt-to-asset ratio (lever)," "the number of directors (directors)," "Proportion of Independent Directors (PID)," "duality of COB and CEO (dual)," "ownership concentration (SF)," "profitability (loss)," "cash flow ratio (cashflow)," "capital occupation (occupy)," "institutional investment (institution)," and "book-to-market ratio (pricebook)."

In addition, this paper also considers including other variables that may be relevant to ESG performance:" Return On Equity (ROE)," "revenue quality (quality)," and" accounting error correction (correction)." ROE reflects the utilization efficiency of an enterprise's assets; Revenue quality represents the dependability of information related to the economic value of an enterprise; accounting error correction may imply the quality and reliability of information disclosure of an enterprise. Therefore, there are reasonable prospects that higher ROE, higher revenue quality, and less accounting error correction will indicate that an enterprise will have a higher industry status and assume more social responsibility, meaning better ESG performance.

The data of control variables are all from the CSMAR database, and details of variables can be seen in Table 1.

TABLE 1 Abbreviations of variables and corresponding names and definitions.

Variable abbr.	Variable name	Variable definition
ESG	ESG performance	ESG ratings from Chindices
DX	Level of digital transformation	Logarithm of frequency of keywords in annual reports
Asset	Enterprise size	Logarithm of total assets in annual reports
Age	Enterprise age	Logarithm of years of being listed as a public company
Lever	Debt-to-asset ratio	Ratio of total debt to total assets
Directors	Number of directors	Logarithm of number of directors
PID	Proportion of Independent Directors	Proportion of independent directors to total directors
Dual	Duality of COB and CEO	Whether COB and CEO are the same person
SF	Ownership concentration	Proportion of shares held by the largest shareholder to total shares outstanding
Loss	Profitability	Whether the net profit the whole year is negative
Cashflow	Cash flow ratio	Ratio of net cash flow from operating activities to total assets
Occupy	Capital occupation	Ratio of other receivables to total assets
Institution	Institutional investment	Proportion of total shares held by institutional investors to total shares outstanding
Pricebook	Book-to-market ratio	Ratio of book value to total market value
ROE	Return On Equity	Ratio of net income to average shareholders' equity
Quality	Revenue quality	Ratio of net revenue to total profits
Correction	Accounting error correction	Whether there exists accounting error correction

4 | RESULTS

This article uses the data of state-owned enterprises listed on the A-share market from 2010 to 2021 as the research sample. Therefore, this article has excluded non-state-owned enterprises and samples delisted during this period.

The descriptive statistics of each variable are shown in Table 2. The mean of the dependent variable ESG is 4.212, with a standard deviation of 1.127. This indicates some difference in ESG performance among different state-owned enterprises, but it is generally at a slightly above-average level. The mean of the core independent variable — DX, which we are interested in, is 2.530, with a standard

TABLE 2 Descriptive statistics of variables.

Classification	Variable	Obs.	Mean	St. dev.	Min.	Max.
Dependent variable	ESG	12,385	4.212	1.127	1	8
	DX	12,065	2.530	1.237	0.000	6.653
Explanatory variable	Asset	12,167	22.901	1.530	19.873	28.513
	Age	12,328	2.570	0.685	0.000	3.332
	Lever	10,819	0.509	0.193	0.082	0.927
	Directors	12,223	2.296	0.230	1.792	2.944
	PID	12,252	0.368	0.059	0.250	0.571
	Dual	12,138	0.098	0.297	0	1
	SF	12,022	0.387	0.148	0.114	0.760
	Loss	12,434	0.111	0.314	0	1
	Cashflow	12,185	0.043	0.065	−0.179	0.233
	Occupy	12,309	0.015	0.021	0.000	0.143
	Institution	12,185	0.503	0.200	0.006	0.923
	Pricebook	12,211	1.728	2.095	0.083	18.993
	ROE	12,108	0.065	0.111	−0.769	0.378
	Quality	12,108	0.305	1.271	−11.393	1.224
	Correction	12,405	0.029	0.167	0	1

deviation of 1.237. This means there is a significant difference in the DX level among enterprises, and there are still quite a few enterprises that have not yet carried out DX.

Based on the characteristic of ESG as an ordered categorical variable, this article will use an Ordered Logistic Model to empirically study the relationship between corporate DX and ESG performance. Firstly, this article sets the latent variable ESG* as a function of DX and control variables:

$$\mathrm{ESG}_{it}^{*} = \alpha + \beta \mathrm{DX}_{it} + \sum_{j} \gamma_j x_{j,it} + \varepsilon_{it}, \tag{9}$$

where ESG_{it}^{*} represents the latent ESG performance of firm i at time t, DX_{it} represents the degree of DX, β is the focus of this paper. Then, the piecewise function of ESG_{it} is constructed using the latent variable ESG_{it}^{*}:

$$\mathrm{ESG}_{it} = \begin{cases} \mathrm{C}, & \mathrm{ESG}_{it}^{*} \le r_1 \\ \mathrm{CC}, & r_1 \le \mathrm{ESG}_{it}^{*} \le r_2 \\ \dots & \\ \mathrm{AA}, & \mathrm{ESG}_{it}^{*} \ge r_k \end{cases}. \tag{10}$$

The Gradient Descent can be used to perform maximum likelihood estimation on the parameters $\theta(\alpha,\beta,\gamma)$, in order to obtain the estimated coefficient of DX. By progressively adding each control variable, this article conducts Ordered Logistic regressions in multiple groups, and the results of each group are shown in Table 3. The following text will collectively refer to these results as the "baseline regression" results.

The results indicate that the coefficients of the DX are significantly positive at the 1% significance level in all groups, which means that the DX of companies should have a significant positive effect on their ESG performance. Moreover, from the specific values of the coefficients of DX in each group, the impact of DX on ESG performance does not show significant differences under different groups. Previous empirical research has shown that the fitting would be well realized while the McFadden pseudo-R^2 is between 0.2 and 0.4. The results also show that the McFadden pseudo-R^2 of all groups are above 0.2, which means that the Ordered Logistic Model used in this study should be sufficiently effective in studying the empirical relationship between DX and ESG performance.

This section also conducts a preliminary robustness check on the baseline regression results using truncation and winsorization. Specifically, the article truncates and winsorizes each variable by 1% and 2.5%, and conducts Ordered Logistic regressions, with all control variables included. The results are shown in Table 4.

The results show that the coefficients of DX are all significantly positive at the 1% level of significance, and the values of the coefficients of DX are consistent with the coefficients displayed by Group (7) in the baseline regression. This means that even in the truncated or winsorized samples, DX also shows a significant positive impact on the ESG performance of enterprises.

However, it should be noted that the coefficients obtained based on the nonlinear model cannot be directly used to explain the magnitude of the independent variables' impacts on the dependent variable. Therefore, based on partial differentiation, this article calculates the marginal effects of various variables on the ESG performance of enterprises:

$$\frac{\partial P(y_i \le k|\mathbf{x})}{\partial x_j} = \frac{\partial \Phi(\boldsymbol{\beta}\mathbf{x}^T)}{\partial x_j} = \frac{\partial \Phi(\boldsymbol{\beta}\mathbf{x}^T)}{\partial(\boldsymbol{\beta}\mathbf{x}^T)} \cdot \frac{\partial(\boldsymbol{\beta}\mathbf{x}^T)}{\partial x_j} = \beta_j \cdot \phi(\boldsymbol{\beta}\mathbf{x}^T). \tag{11}$$

TABLE 3 Baseline results of ordered logistic regressions.

Variable	ESG (1)	(2)	(3)	(4)	(5)	(6)
DX	0.216***	0.128***	0.125***	0.123***	0.123***	0.123***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Asset		0.485***	0.484***	0.462***	0.417***	0.417***
		(0.015)	(0.015)	(0.016)	(0.019)	(0.019)
Age		−0.110***	−0.117***	−0.101***	−0.112***	−0.111***
		(0.033)	(0.033)	(0.034)	(0.034)	(0.034)
Lever		−1.525***	−1.530***	−1.329***	−1.286***	−1.287***
		(0.099)	(0.099)	(0.105)	(0.111)	(0.111)
Directors			−0.278***	−0.244***	−0.265***	−0.262***
			(0.080)	(0.080)	(0.080)	(0.080)
PID			2.441***	2.487***	2.542***	2.540***
			(0.291)	(0.291)	(0.292)	(0.292)
Dual			−0.117*	−0.116*	−0.108*	−0.109*
			(0.061)	(0.062)	(0.062)	(0.062)
SF				0.005	−0.277**	−0.280**
				(0.129)	(0.139)	(0.139)
Loss				−0.603***	−0.593***	−0.589***
				(0.062)	(0.062)	(0.062)
Cashflow				−0.351	−0.540**	−0.556**
				(0.265)	(0.268)	(0.268)
Occupy					−3.046***	−3.050***
					(0.630)	(0.631)
Institution					0.006***	0.006***
					(0.001)	(0.001)
Pricebook					0.031**	0.031**
					(0.013)	(0.013)
ROE						0.039**
						(0.018)
Quality						−0.0002
						(0.002)
Correction						−0.028
						(0.106)
Observations	10,181	10,181	10,181	10,181	10,181	10,181
Time FEs	×	×	×	×	×	×
Individual FEs	×	×	×	×	×	×
McFadden R^2	0.202	0.232	0.235	0.237	0.239	0.239
LR statistic	16.61	24.11	12.31	17.50	34.47	33.11

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 5 shows the marginal effects of five groups, including Group (7) in the baseline regression, and 1%/2.5% truncation/winsorization samples corresponding. However, due to space limitations, this article only displays the marginal effects of the DX.

The results show that, for the baseline regression, when the ESG is 1/2/3/4 (ESG ratings of C/CC/CCC/B), the coefficient of DX is significantly negative at the 1% level of significance; while when the ESG is 5/6/7/8 (ESG ratings of BB/BBB/A/AA), the coefficient of DX is significantly positive at the 1% level of significance. This means that DX has a significant positive marginal effect on better ESG performance, while it has a significant negative marginal effect on worse ESG performance. In other words, DX can enhance the probability of

TABLE 4 Results based on truncation and winsorization.

	ESG			
Variable	1% truncated (1)	2.5% truncated (2)	1% winsorized (3)	2.5% winsorized (4)
DX	0.116***	0.135***	0.123***	0.124***
	(0.018)	(0.023)	(0.016)	(0.016)
Asset	0.385***	0.355***	0.390***	0.393***
	(0.022)	(0.028)	(0.019)	(0.020)
Age	−0.095**	−0.072	−0.079**	−0.070**
	(0.038)	(0.045)	(0.034)	(0.034)
Lever	−1.089***	−1.069***	−1.154***	−1.197***
	(0.133)	(0.168)	(0.115)	(0.119)
Directors	−0.225**	−0.305**	−0.236***	−0.237***
	(0.095)	(0.122)	(0.081)	(0.084)
PID	2.562***	2.869***	2.780***	2.932***
	(0.355)	(0.484)	(0.304)	(0.313)
Dual	−0.102	−0.191**	−0.123**	−0.123**
	(0.068)	(0.080)	(0.062)	(0.062)
SF	−0.292*	−0.423**	−0.305**	−0.298**
	(0.160)	(0.198)	(0.141)	(0.143)
Loss	−0.266***	−0.256***	−0.363***	−0.322***
	(0.076)	(0.093)	(0.065)	(0.065)
Cashflow	−0.893***	−1.375***	−0.893***	−1.018***
	(0.339)	(0.447)	(0.285)	(0.303)
Occupy	−1.652	−2.465	−2.940***	−2.901***
	(1.030)	(1.603)	(0.792)	(0.935)
Institution	0.005***	0.003**	0.005***	0.005***
	(0.001)	(0.002)	(0.001)	(0.001)
Pricebook	0.037**	0.042*	0.041***	0.043***
	(0.017)	(0.025)	(0.014)	(0.017)
ROE	2.359***	3.229***	1.873***	2.570***
	(0.226)	(0.348)	(0.161)	(0.207)
Quality	0.071***	0.117***	0.055***	0.092***
	(0.018)	(0.033)	(0.012)	(0.018)
Correction	−0.042	−0.018	−0.021	−0.007
	(0.117)	(0.137)	(0.106)	(0.106)
Observations	8800	6681	10,248	10,248
Time FEs	×	×	×	×
Individual FEs	×	×	×	×
McFadden R^2	0.319	0.484	0.235	0.252
LR statistic	13.20	14.70	32.41	27.83

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

an enterprise's acting better ESG performance; namely, DX plays a facilitating role in enterprises' ESG performance. From the results of the four groups based on the 1%/2.5% truncation/winsorization, although the three cases—ESG ratings of C/A/AA, are excluded, the marginal effects of DX on the ESG performance of enterprises in the remaining five cases are basically consistent with the results shown in the baseline regression.

5 | RESULTS ON ROBUSTNESS CHECKS

5.1 | Time-lag effect

Considering introducing lagged variables of the DX into the Ordered Logistic Model, namely while constructing the latent variable, the DX is replaced by its lagged variable of DX_1, DX_2, and DX_3:

TABLE 5 The marginal effects of the DX.

	Baseline (1)	1% truncated (2)	2.5% truncated (3)	1% winsorized (4)	2.5% winsorized (5)
ESG = 1	−0.001***	-	-	−0.001***	-
	(0.000)	-	-	(0.000)	-
ESG = 2	−0.004***	−0.003***	−0.004***	−0.004***	−0.005***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)
ESG = 3	−0.014***	−0.014***	−0.016***	−0.014***	−0.014***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
ESG = 4	−0.010***	−0.011***	−0.013***	−0.010***	−0.011***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
ESG = 5	0.019***	0.019***	0.022***	0.019***	0.020***
	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)
ESG = 6	0.010***	0.009***	0.010***	0.010***	0.010***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
ESG = 7	0.001***	-	-	-	-
	(0.000)	-	-	-	-
ESG = 8	0.000**	-	-	-	-
	(0.000)	-	-	-	-

**$p < 0.05$; ***$p < 0.01$.

TABLE 6 Results on time-lag effect.

	ESG					
Variable	(1)	(2)	(3)	(4)	(5)	(6)
DX_1	0.255***			0.150***		
	(0.017)			(0.019)		
DX2		0.244***			0.146***	
		(0.017)			(0.019)	
DX_3			0.230***			0.145***
			(0.017)			(0.019)
Observations	10,656	9371	8194	9275	8166	7128
Time FEs	×	×	×	×	×	×
Individual FEs	×	×	×	×	×	×
McFadden R^2	0.145	0.244	0.337	0.304	0.383	0.459
LR statistic	15.74	8.12	5.02	46.67	60.08	49.28

***$p < 0.01$.

$$\begin{cases} ESG^*_{it} = \alpha + \beta DX\_1_{it} + \sum_j \gamma_j x_{j,it} + \varepsilon_{it} \\ ESG^*_{it} = \alpha + \beta DX\_2_{it} + \sum_j \gamma_j x_{j,it} + \varepsilon_{it} \\ ESG^*_{it} = \alpha + \beta DX\_3_{it} + \sum_j \gamma_j x_{j,it} + \varepsilon_{it} \end{cases}. \tag{12}$$

The regression results are shown in Table 6, where Groups (1–3) include only the core independent variable—DX, while Groups (4–6) include all control variables.

The results show that DX_1, DX_2, and DX_3 are all significantly positive at the 1% level, indicating that the positive impact of the DX on ESG performance has a very significant time-lag effect. Moreover, there is no significant difference between the coefficients of DX_1, DX_2, and DX_3, suggesting that the positive impact of DX on the ESG performance may not only be significant but also have a long-time span. That is, after the DX of an enterprise, its ESG performance can continue to be positively promoted by DX for a considerable period of time.

5.2 | Endogeneity issue

5.2.1 | Two-way fixed effect

In order to control for variables which do not vary across individuals and time, this article considers directly introducing the two-way fixed effect into the logistic model, by:

$$ESG^*_{it} = \alpha + \beta DX_{it} + \sum_j \gamma_j x_{j,it} + \lambda_t + \mu_i + \varepsilon_{it}, \tag{13}$$

TABLE 7 Results of two-way fixed effect and two-stage regression.

	ESG			
	TWFE	TSLS	Ordered Logistic	
Variable	(1)	(2)	(3)	(4)
3 DX	0.058***			
	(0.013)			
$\widetilde{\mathrm{DX}}$		0.081***	0.178***	0.187***
		(0.015)	(0.023)	(0.023)
Observations	10,181	9060	9060	7908
Time FEs	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓
McFadden R^2	-	-	0.054	0.054
LR statistic	-	-	50.39	49.47
R^2	0.033	0.033	-	-
F Statistic	19.26	16.89	-	-

***$p < 0.01$

where λ_t represents the time fixed effect and μ_i represents the individual fixed effect. In fact, the introduction of the two-way fixed effect can usually be achieved through within-group deviation transformation. Specifically, by assuming ESG_{it}^* is the observable variable, firstly grouping the ESG_{it}^*, DX_{it}, and the control variables by individual and time; and then calculating the time average taken for each variable grouped by individual and the individual average taken for each variable grouped by time; and finally calculating the average of each variable over the entire population:

$$\begin{cases} \overline{\mathrm{ESG}}_i^* = \beta\overline{\mathrm{DX}}_i + \sum_j \gamma_j \overline{x}_{j,i} + \overline{\lambda} + \mu_i + \overline{\varepsilon}_i \\ \overline{\mathrm{ESG}}_t^* = \beta\overline{\mathrm{DX}}_t + \sum_j \gamma_j \overline{x}_{j,t} + \lambda_t + \overline{\mu} + \overline{\varepsilon}_t \\ \overline{\mathrm{ESG}}^* = \beta\overline{\mathrm{DX}} + \sum_j \gamma_j \overline{x}_j + \overline{\lambda} + \overline{\mu} + \overline{\varepsilon} \end{cases}. \tag{14}$$

And then λ_t and μ_i can be eliminated:

$$\widetilde{\mathrm{ESG}}_{it}^* = \beta\widetilde{\mathrm{DX}}_{it} + \sum_j \gamma_j \widetilde{x}_{j,it} + \widetilde{\varepsilon}_{it}, \tag{15}$$

where $\widetilde{\mathrm{ESG}}_{it}^* = \mathrm{ESG}_{it}^* - \overline{\mathrm{ESG}}_i^* - \overline{\mathrm{ESG}}_t^* + \overline{\mathrm{ESG}}^*$; $\widetilde{\mathrm{DX}}_{it} = \mathrm{DX}_{it} - \overline{\mathrm{DX}}_i - \overline{\mathrm{DX}}_t + \overline{\mathrm{DX}}$; $\widetilde{x}_{it} = x_{it} - \overline{x}_i - \overline{x}_t + \overline{x}$; $\widetilde{\varepsilon}_{it} = \varepsilon_{it} - \overline{\varepsilon}_i - \overline{\varepsilon}_t + \overline{\varepsilon}$. Worthing mentioning, at this point, although the latent variable $\widetilde{\mathrm{ESG}}_{it}^*$ can still be treated as an ordinal categorical variable, the number of its categories is much larger than the original latent variable, and can be considered as a quantitative variable. Therefore, in this article, the within-group deviation transformation is directly applied to ESG, DX, and control variables, and the within-group OLS estimation is directly based on Equation (15), namely $\widehat{\beta}^{\text{within}} = \left(\widetilde{\boldsymbol{X}}^T\widetilde{\boldsymbol{X}}\right)^{-1}\left(\widetilde{\boldsymbol{X}}^T\widetilde{\boldsymbol{Y}}\right)$. Where $\widetilde{\boldsymbol{X}} = \left\{\widetilde{\mathbf{DX}}, \widetilde{\boldsymbol{x}}\right\}^T$, $\widetilde{\boldsymbol{Y}} = \widetilde{\mathbf{ESG}}^T$, and $\widehat{\beta}^{\text{within}}$ is the within-group estimator. The results of the within-group estimator of DX will be presented together with the two-stage regression results in the following, as shown in Table 7.

5.2.2 | Two-stage regression

As demonstrated by the results of the baseline regression, the DX of enterprises has a significant positive effect on their ESG performance. However, it cannot be ruled out that some enterprises with better ESG performance may also be more inclined to undergo higher levels of DX. Therefore, this article considers introducing instrumental variables into the model and conducting two-stage regression to address the endogeneity that may arise from possible reverse causality. This article first selects lagged variables of DX — DX_1 as instrumental variables and conducts first-stage estimation on panel data based on mixed effects.

$$\mathrm{DX}_{it} = \alpha^{\mathrm{tsls}_1} + \beta^{\mathrm{tsls}_1}\mathrm{DX\_1}_{it} + \sum_j \gamma_j^{\mathrm{tsls}_1} x_{j,it} + \varepsilon_{it}. \tag{16}$$

Subsequently, this article conducts second-stage regression using OLS based on the variables which has undergone within-group deviation transformation:

$$\mathrm{ESG}_{it}^* = \alpha^{\mathrm{tsls}_2} + \beta^{\mathrm{tsls}_2}\widetilde{\mathrm{DX}}_{it} + \sum_j \gamma_j^{\mathrm{tsls}_2} x_{j,it} + \varepsilon_{it}, \tag{17}$$

where $\widetilde{\mathrm{DX}}_{it} = \widehat{\alpha}^{\mathrm{tsls}_1} + \widehat{\beta}^{\mathrm{tsls}_1}\mathrm{DX}_{1it} + \sum_j \widehat{\gamma}_j^{\mathrm{tsls}_1} x_{j,it} + \widehat{\varepsilon}_{it}$, and the focus of this article is on estimating β^{tsls_2}. Besides that, this article constructs latent variables based on the instrumental variables—DX_1 and DX_2, and re-conducts second-stage regression using an Ordered Logistic regression.

$$\mathrm{ESG}_{it}^* = \widehat{\alpha}^{\mathrm{tsls}_2} + \widehat{\beta}^{\mathrm{tsls}_2}\widetilde{\mathrm{DX}}_{it} + \sum_j \widehat{\gamma}_j^{\mathrm{tsls}_2} x_{j,it} + \varepsilon_{it}. \tag{18}$$

The results show that the coefficients for DX in each group are significantly positive at the 1% level. Furthermore, by comparing the plus/minus signs, specific values, and significance of other control variables, it can be observed that there is no significant difference in the results among the different groups under the same estimation approach. It means that even after considering the potential endogeneity, the positive impact of DX on ESG performance is still significant.

5.2.3 | Differences-in-differences

The control of the two-way fixed effect on omitted variables bias is relatively limited. Therefore, this study considers combining propensity score matching (PSM) and staggered differences-in-differences (staggered DID) for ordered logistic regression.

This paper will use three different methods to obtain the PSM sample set: firstly, this article will select caliper-nearest matching as the method for propensity value matching, and choose generalized linear model (GLM) as the measure of distance, and set the caliper to 20%, which means that sample with matching distance exceeding 20% will be discarded; secondly, this article will still choose caliper-nearest matching, but choose Mahalanobis distance as the measure of distance, and obtain the second sample set; finally, this article will choose subclass matching as the matching method, and also choose GLM as the measure of distance, to obtain the third sample set.

In order to introduce staggered DID into the Ordered Logistic Model and use the sample data based on PSM for regression, this article introduces the interaction term $\text{treat}_i \times \text{post}_{it}$ in the construction of latent variable:

$$\text{ESG}_{it}^{*} = \alpha^{\text{did}} + \beta^{\text{did}} \text{treat}_i \times \text{post}_{it} + \sum_j \gamma_j^{\text{did}} x_{j,it} + \lambda_t + \mu_i + \varepsilon_{it}. \tag{19}$$

In addition, this article also introduces DX_{it} in the interaction term to reflect the degree of DX of the enterprise:

$$\text{ESG}_{it}^{*} = \alpha^{\text{did}} + \beta^{\text{did}} \text{treat}_i \times \text{post}_{it} \times \text{DX}_{it} + \sum_j \gamma_j^{\text{did}} x_{j,it} + \lambda_t + \mu_i + \varepsilon_{it}, \tag{20}$$

where λ_t denotes the time fixed effect and μ_i denotes the individual fixed effect. In order to preserve the property of the ESG as a categorical variable and to continue to use Ordered Logistic regression, this article considers using the Least Squares Dummy Variable (LSDV) to introduce two-way fixed effects in the process of constructing the latent variable.

$$\begin{cases} \text{ESG}_{it}^{*} = \alpha^{\text{did}} + \beta^{\text{did}} \text{treat}_i \times \text{post}_{it} + \sum_j \gamma_j^{\text{did}} x_{j,it} \\ \qquad + \sum_{n=1}^{N-1} \delta_n^{(N)} D_n^{(N)} + \sum_{t=1}^{T-1} \delta_t^{(T)} D_t^{(T)} + \varepsilon_{it} \\ \text{ESG}_{it}^{*} = \alpha^{\text{did}} + \beta^{\text{did}} \text{treat}_i \times \text{post}_{it} \times \text{DX}_{it} + \sum_j \gamma_j^{\text{did}} x_{j,it} \\ \qquad + \sum_{n=1}^{N-1} \delta_n^{(N)} D_n^{(N)} + \sum_{t=1}^{T-1} \delta_t^{(T)} D_t^{(T)} + \varepsilon_{it} \end{cases}, \tag{21}$$

where D^N denotes the individual dummy variable, D^T denotes the time dummy variable. The results based on the PSM and Staggered DID are shown in Tables 8 and 9, with all control variables included. Group (1) in Tables 8 and 9. correspond to the results of introducing $\text{treat}_i \times \text{post}_{it}$. Groups (2–4) correspond to the regression results after introducing $\text{treat}_i \times \text{post}_{it} \times \text{DX}_{it}$. Furthermore, Group (2), Group (3), and Group (4) correspond to the results based on caliper-nearest matching with GLM, caliper-nearest matching with Mahalanobis Distance, and subclass matching with GLM respectively.

The results indicate that $\text{treat}_i \times \text{post}_{it}$ of all groups are significantly positive, at least at a 10% significance level, and the coefficients of $\text{treat}_i \times \text{post}_{it} \times \text{DX}_{it}$ are all significantly positive at a 1% significance level. This suggests that, after fully considering and eliminating endogeneity, the DX of enterprises still has a significant positive impact on their ESG performance. Moreover, the results also indicate that even without considering the degree of DX, as long as an enterprise undergoes the DX, it will be expected to have a significant positive impact on its ESG performance.

5.3 | Dependent variable replacement

This article first replaced the dependent variable—ESG performance of companies. In fact, the ESG ratings of companies can vary widely due to different scoring criteria, industry adjustments, and data sources, resulting in low levels of correlation between ESG ratings provided by different rating companies (Chatterji et al., 2016). Therefore, a robustness test based on replacing the dependent variable should be sufficiently practical. Thus, this article firstly selects another two indicators as "categorical variables" used in the baseline regression, which measures the ESG performance through "ratings"—including Wind ESG ratings and SynTao Green Finance ESG ratings, and still adopts the Ordered Logistic Model in the regression. Then, this article selects a "quantitative indicator," which measures the ESG performance through "scores"—Bloomberg ESG scores, but conducts the OLS regression based on the two-way fixed effect. Results are shown in Table 10. with all control variables introduced for each group.

TABLE 8 Results of DID based on OLS and two-way fixed effect.

	ESG			
Variable	(1)	(2)	(3)	(4)
Treat × post	0.117**			
	(0.058)			
Treat × post × DX		0.064***	0.071***	0.072***
		(0.018)	(0.017)	(0.018)
Observations	6636	4716	6636	4958
Time FEs	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓
Adjusted R^2	0.024	0.023	0.025	0.024
F statistic	11.04	7.987	11.85	8.705

$^{**}p < 0.05$; $^{***}p < 0.01$.

TABLE 9 Results of DID based on ordered logistic and two-way fixed effect.

	ESG			
Variable	(1)	(2)	(3)	(4)
Treat × post	0.205**			
	(0.091)			
Treat × post × DX		0.319***	0.240***	0.492***
		(0.069)	(0.059)	(0.065)
Observations	6636	4716	6636	4958
Time FEs	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓
McFadden R^2	0.367	0.388	0.367	0.386
LR statistic	45.32	30.71	43.76	35.18

$^{**}p < 0.05$; $^{***}p < 0.01$.

TABLE 10 Results of robustness checks based on dependent variable replacement.

	Wind ESG	SynTao ESG	Bloomberg ESG
	Ordered logistic		TWFE
Variable	(1)	(2)	(3)
DX	0.092**	0.242***	0.450***
	(0.044)	(0.029)	(0.096)
Observations	1571	3688	5136
Time FEs	✓	✓	✓
Individual FEs	✓	✓	✓
McFadden R^2	0.263	0.241	-
Adjusted R^2	-	-	0.023
LR statistic	38.09	34.64	-
F statistic	-	-	6.529

$^{**}p < 0.05$. $^{***}p < 0.01$.

TABLE 11 Results of robustness checks based on core explanatory variable replacement.

	ESG			
Variable	(1)	(2)	(3)	(4)
DTA	0.169***			
	(0.032)			
IBM		0.130***		
		(0.032)		
IM			0.053*	
			(0.032)	
MIS				0.122***
				(0.032)
Observations	3462	3462	3462	3462
Time FEs	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓
McFadden R^2	0.064	0.061	0.059	0.060
LR statistic	33.52	20.84	28.21	32.34

$^{*}p < 0.1$; $^{***}p < 0.01$.

The results show that the coefficients of DX still have significantly positive values at a high level of significance in each group, which means that the positive impact of DX on ESG performance is robust and reliable; namely, the significant effect of this positive impact does not disappear with changes in evaluation criteria and measurements on ESG.

5.4 | Core explanatory variable replacement

Referring to the approach on constructing the DX, the article constructs "key words" dictionaries from four dimensions: "digital technology application" (DTA), "internet business model" (IBM), "intelligent manufacturing" (IM), and "modern information system" (MIS), and logarithmically processes the word frequency for the four categories of words. Then, the logarithmic indicators corresponding to the four categories of word frequency are used as the replacement indicator for the DX, and Ordered Logistic regressions are conducted again. The results are shown in Table 11, with all control variables introduced for each group.

The results show that the replacement indicator for the DX in each group is significantly positive at a high level, which means that regardless of how the degree of DX is measured, the positive impact of DX on ESG performance is also robust and reliable.

6 | RESULTS ON HETEROGENEITY AND MODERATING EFFECT

6.1 | Heterogeneity analysis

6.1.1 | Grouping based on high-tech

As non-high-tech industries are usually linked with those production and operation modes being relatively traditional and backward, there is lack of digital technology applications and technological intensity of productions, which may result in more room for DX (Pronchakov et al., 2022). Therefore, the integration of traditional industries with digital technology may improve their production and operation management efficiency in a further step. However, it is worthy noting that most high-tech state-owned enterprises were founded just for strategic emerging industries in recent years, meaning that they are faced with high pressure of social responsibility determined by their original intention and mission of establishment; additionally, such enterprises may have more capabilities in realizing effective and reasonable utilization of digital techniques. Therefore, enterprises located in high-tech industries will be more likely to have better ESG performance through DX integration, compared to non-high-tech ones.

Referring to the industrial classification for national economic activities (GB/T 4754-2017) and documents titled" High-tech industries (manufacturing/service industry) category" proclaimed by National Bureau of Statistics (NBS), this article identifies high-tech (i.e., if_hightech = 1) and non-high-tech (i.e., namely if_hightech = 0) enterprises, based on whether they are located in the high-tech industries (bio-pharmaceutics, electronics, computer, communication, armariums, spacecraft, etc.); and then conduct grouped regressions based on the Ordered Logistic Model.

6.1.2 | Grouping based on marketization

The promotion effect of DX on ESG performance in enterprises may vary under different degrees of marketization. Marketization indicates the sensitivity to changes in supply and demand forces, implying that the higher the level of marketization in which an enterprise operates within its industry or region, the more sensitive the enterprise's response to changes in supply and demand. This suggests that the enterprise may possess a well-developed feedback mechanism and information transmission system, attributed to the enterprise's existing comprehensive digital information platform. Higher levels of marketization may also require companies to have a sufficient level of information disclosure. Therefore, higher degrees of marketization may imply a lower promotion effect of DX on ESG performance.

This article uses the NERI Index of Marketization, measured by Fan et al. (2019), to measure the level of marketization. This indicator evaluates the marketization from five aspects (e.g., the relationship between government and market, the development of factor markets). The larger the index, the higher the level of marketization. In this paper, enterprises with a marketization index higher than or equal to the median value are classified as high marketization (if_highmarketize = 1), otherwise, they are classified as low marketization (if_highmarketize = 0); and then, this article conducts grouped regressions based on the Ordered Logistic Model.

6.1.3 | Grouping based on life cycle

For enterprises in the growth stage, DX can create more economic value and accelerate the growth of emerging enterprises. For those in the decline stage, DX can transform outdated business models, enable them to survive, create more emerging economic value, and reverse the decline trend. For those in the maturity stage, they have a large amount of funds and stable cash flow. When these enterprises undergo DX, they have the capabilities to create more economic value, but at the same time, they will face more non-performance-related pressures, which means that they are encouraged to take on more social responsibility, thus exhibiting a better promotion effect of DX on ESG performance.

Referring to Abdel-Wanis (2020) and Han and Jung (2022), this paper divides the enterprise life cycle into growth stage (i.e., life_cycle = 1), maturity stage (i.e., life_cycle = 2), and decline stage (i.e., life_cycle = 3), based on the type of cash flow portfolio, and conducts grouped regressions though the Ordered Logistic Model.

All results of grouped regressions are shown in Table 12, with all control variables included.

The results show that the coefficients of DX in all seven groups are significantly positive at the level of at least 10%, meaning that This shows that DX can always improve the ESG performance of each category of state-owned enterprises, regardless of the grouping criterion. However, the results do not reveal whether DX's promoting effect on ESG performance differs between different categories of state-owned enterprises. Thus, in order to compare whether there are differences in the coefficients of DX between different groups, this article calculates the 97.5% confidence interval. Besides that, this article also calculates the empirical p-value of different regressions for DX through the Fisher Permutation Test based on Bootstrap Sampling. Specifically, this article conducts the Fisher Permutation Test based on 1000 times Bootstrap Sampling between the regression results of sub-samples within the same grouping criterion and then obtains empirical *p*-values. Results are shown in Table 13.

The results show that, based on the classification of whether the enterprise belongs to the high-tech industry, the empirical p-value of the DX difference between groups is 0.001, which means that the impact of DX on ESG performance does not have significant inter-group differences; namely, ESG performance of enterprises located in high-tech industries can be significantly promoted by DX at a higher level than those in non-high-tech. Based on the classification of whether the enterprise is high-marketized, the empirical p-value is 0.059, indicating that the DX carried out by non-high-marketized enterprises can also promote their ESG performance at a higher level. Finally, based on the classification of the life cycle, there is almost no overlap in the 97.5% confidence intervals of DX between the samples of the growth stage and maturity stage, as well as between the samples of the maturity stage and decline stage, and the empirical p-values also show that the inter-group differences between them are significant at the 1% level. This suggests that the DX carried out by enterprises located in the maturity stage can promote their ESG performance more significantly, compared to those in the growth and decline stages.

TABLE 12 Results of grouped regressions.

	ESG						
	High-tech		Marketization		Life cycle		
	Low	High	Low	High	Growth	Maturity	Decline
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DX	0.071***	0.159***	0.136***	0.085***	0.081***	0.202***	0.067*
	(0.023)	(0.024)	(0.019)	(0.028)	(0.024)	(0.025)	(0.034)
Observations	6220	3961	7037	3144	4074	4005	2039
Time FEs	✓	✓	✓	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓	✓	✓	✓
McFadden R^2	0.251	0.231	0.245	0.228	0.240	0.195	0.309
LR statistic	24.89	32.60	21.41	10.60	10.73	17.64	10.19

*$p < 0.1$; ***$p < 0.01$.

TABLE 13 Results of Fisher Permutation Test.

Criterion	Group	Est.	Conf.lwr	Conf.upr	Empirical *p*-value
High-tech	Low	0.071***	0.020	0.123	[0.001]
	High	0.159***	0.106	0.212	
Marketization	Low	0.136***	0.094	0.178	[0.059]
	High	0.085***	0.023	0.148	
Life cycle	Growth	0.081***	0.026	0.136	[0.001]
	Maturity	0.202***	0.146	0.259	[0.011]
	Decline	0.067*	−0.010	0.145	

*$p < 0.1$; ***$p < 0.01$.

TABLE 14 Results of introducing the moderating effect.

	ESG			
	if_mix		Balance	
Variable	(1)	(2)	(3)	(4)
if_mix	−0.498***	−0.545***		
	(0.124)	(0.140)		
balance			−0.857***	−0.976***
			(0.226)	(0.260)
DX	0.098***	0.092***	0.114***	0.113***
	(0.026)	(0.030)	(0.028)	(0.033)
if_mix × DX	0.148***	0.167***		
	(0.040)	(0.047)		
Balance × DX			0.138*	0.160*
			(0.073)	(0.086)
Observations	6522	4842	6522	4842
Time FEs	✓	✓	✓	✓
Individual FEs	✓	✓	✓	✓
McFadden R^2	0.054	0.047	0.054	0.047
LR statistic	32.87	16.89	48.91	17.55

*$p < 0.1$; ***$p < 0.01$.

TABLE 15 Results of the marginal effects of introducing the moderating effect.

	if_mix		Balance	
	(1)	(2)	(3)	(4)
ESG = 1	−0.001***	−0.001***	−0.001***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
ESG = 2	−0.003***	−0.003***	−0.003***	−0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
ESG = 3	−0.011***	−0.010***	−0.012***	−0.012***
	(0.003)	(0.003)	(0.003)	(0.004)
ESG = 4	−0.010***	−0.008***	−0.011***	−0.010***
	(0.003)	(0.003)	(0.003)	(0.003)
ESG = 5	0.014***	0.014***	0.017***	0.017***
	(0.004)	(0.005)	(0.004)	(0.005)
ESG = 6	0.009***	0.008***	0.010***	0.010***
	(0.002)	(0.003)	(0.003)	(0.003)
ESG = 7	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
ESG = 8	0.000*	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)

*$p < 0.1$; ***$p < 0.01$.

6.2 | Moderating effect analysis

In order to investigate the moderating effect of a moderator on the relationship between enterprises' DX and their ESG performance. This article introduces the moderator variable (Mod_{it}) and the interaction term $\mathrm{DX}_{it} \times \mathrm{Mod}_{it}$, while constructing the latent variable; and then conducts Ordered Logistic regressions to analyze the moderating effect:

$$\mathrm{ESG}_{it}^{*} = \alpha^{\mathrm{mod}} + \beta_1^{\mathrm{mod}}\mathrm{DX}_{it} + \beta_2^{\mathrm{mod}}\mathrm{Mod}_{it} + \beta_3^{\mathrm{mod}}\mathrm{DX}_{it} \times \mathrm{Mod}_{it} + \sum_j \gamma_j^{\mathrm{mod}} x_{j,it} + \varepsilon_{it}. \tag{22}$$

The moderating effect focuses on the coefficient β_3^{mod}. The moderator variable will have a significant moderating effect on the relationship between the core independent variable and the dependent variable, while β_3^{mod} is significant. Equation (22) can also be rewritten as:

$$\mathrm{ESG}_{it}^{*} = \left(\alpha^{\mathrm{mod}} + \beta_2^{\mathrm{mod}}\mathrm{Mod}_{it}\right) + \left(\beta_1^{\mathrm{mod}} + \beta_3^{\mathrm{mod}}\mathrm{Mod}_{it}\right)\mathrm{DX}_{it} + \sum_j \gamma_j^{\mathrm{mod}} x_{j,it} + \varepsilon_{it}, \tag{23}$$

where $\left(\beta_1^{\mathrm{mod}} + \beta_3^{\mathrm{mod}}\mathrm{Mod}_{it}\right)$ denotes the Simple Slope, which reflects how the relationship between ESG and DX is moderated by the moderator.

This article introduces" if_mix" (i.e., whether an enterprise is mixed-ownership) and" balance" (i.e., the degree of equity balance) as moderator variables. First, the Company Law of the PRC stipulates

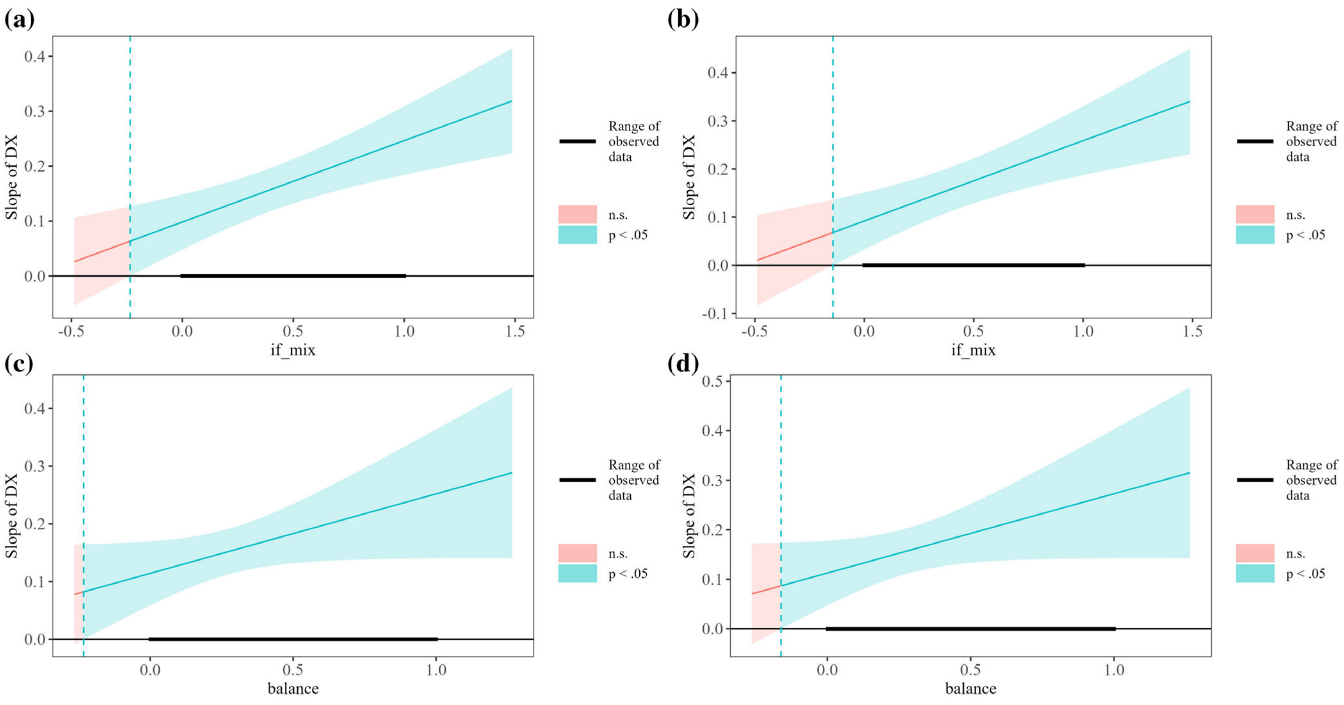

FIGURE 1 Johnson–Neyman plots.

that shareholders holding more than 10% of the company's shares individually or jointly have the right to request the board of directors to convene an extraordinary general meeting of shareholders. It means that the voice of participating shareholders is significantly enhanced when their shareholding proportion exceeds 10%. Therefore, this article judges whether the company is mixed-ownership based on judging whether the proportion of non-state-owned shareholders among the top 10 shareholders exceeds 10%, that is, if_mix $=1$ when the enterprise is mixed-ownership, otherwise if_mix $=0$. Second, in the process of mixed-ownership reform of state-owned enterprises, the participation of non-state-owned capital shareholders has improved the diversity of ownership structure and promoted the balance between state-owned and non-state-owned capital (Wu and Li, 2023). Therefore, this article uses the proportion of total equity of non-state-owned shareholders (among the top 10 shareholders) to total equity of the largest shareholder as a measure of equity balance, to reflect the voice and supervision of non-state-owned capital in the mixed-ownership reform. The higher the value of "balance," the more the enterprise's equity is dispersed.

The results are shown in Table 14. Groups (1) and (3) only introduce DX as the independent variable in regressions, while groups (2) and (4) introduce all control variables in regressions.

The results show that the coefficients of if_mix $\times$ DX and balance $\times$ DX are both significantly positive, at least at the 10% significance level, which means that mixed-ownership (if_mix $=1$) and higher levels of equity balance have a positive moderating effect on the relationship between DX and ESG performance. In order to compare the impact of DX on ESG performance after introducing moderator variables, this article still calculates the marginal effects of independent variables. Results are shown in Table 15, but due to the limit of the table length, only the marginal effects of DX are shown in the table.

The results show that, for the cases where ESG is 1/2/3/4, the marginal effect of DX remains significantly negative at the 1% level, and for the cases where ESG is 5/6/7/8, the marginal effect of DX remains almost significantly positive at the 1% level, which is consistent with the results of the baseline regression.

Finally, this paper conducts a Johnson–Neyman test on the Simple Slope $\beta_1^{mod}+\beta_3^{mod}\mathrm{Mod}_{it}$ of DX to determine the boundary of the moderating variable value that makes the simple slope significantly different from zero. This article directly presents the Johnson-Neyman plot for the simple slopes under the two different cases of moderating variables — "if_mix" and "balance." The results are shown in Figure 1.

The plots show that, the simple slopes obtained from the Ordered Logistic regressions are all significantly positive at the 5% level. Moreover, as the observation values of the moderating variables increase, the simple slope shows a linear amplification trend, indicating that the mixed ownership and the level of equity balance have positive moderating effects on the relationship between DX and ESG performance.

7 | CONCLUSION

This article selects listed state-owned enterprises in the A-share market of China from 2010 to 2021 as the research sample, to empirically examine the impact of DX of state-owned enterprises on their ESG performance and the moderating effect of mixed-ownership reform on this impact. The results show that: first, the DX of state-owned enterprises can indeed improve their ESG performance, and the positive impact of DX on ESG performance has a significant time-lag effect. This means that, for a considerable period after DX, state-owned enterprises can still receive a positive promotion on their ESG performance. Second, for state-owned enterprises belonging to high-tech industries, with higher level of marketization, or in the maturity stage, DX shows a more substantial promoting effect on their ESG performance, than those belonging to non-high-tech industries, with lower level of marketization, or in the growth and decline stages. Third, mixed ownership and higher levels of equity balance demonstrate a significant positive moderating effect, indicating that mixed-ownership reform can indeed amplify the positive impact of DX on the ESG performance of state-owned enterprises.

Given the above research conclusions, this article proposes the following policy recommendations: first, further promote the top-level DX design in state-owned enterprises. DX is a comprehensive and profound transformation of enterprises rather than a simple application of digital technology, so targeted guidance and instruction are needed for different state-owned enterprises. Second, strengthen the construction of digital infrastructure in state-owned enterprises and build a DX ecosystem. Third, actively promote state-owned enterprises to take the path of ecological priority and green development, fulfill social responsibilities, and play the role of stabilizers and mainstays of the state-owned economy. Finally, continue to deepen the mixed-ownership reform of state-owned enterprises, ensure the supervision and discourse power of non-state-owned shareholders, and leverage the effect of a diversified equity structure to improve corporate efficiency and optimize corporate governance.

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How to cite this article: Zhang, S. (2024). The impact of digital transformation on ESG performance and the moderation of mixed-ownership reform: The evidence from Chinese state-owned enterprises. *Corporate Social Responsibility and Environmental Management*, *31*(3), 2195–2210. https://doi.org/10.1002/csr.2656