

The Impact of Digital-Intelligent Transformation on ESG Performance

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Abstract

With increasingly intense market competition, the digital economy is deeply integrated with the real economy, and the requirements of enterprises for sustainable development continue to upgrade. Digital-intelligent transformation is becoming an important driving factor for the improvement of enterprise ESG performance. This study takes China's A-share listed companies in 2015-2024 as a research sample, and empirically examines the impact and underlying mechanism of digital-intelligent transformation on enterprise ESG performance. The study found that digital-intelligent transformation can significantly promote the improvement of the ESG performance of enterprises by alleviating financing constraints and improving the quality of internal control. This conclusion is still valid after endogeneity tests and a series of robustness tests. And after heterogeneity analysis, the positive effect is more prominent in non-state-owned enterprises, enterprises in the northern China and high-tech enterprises. At the theoretical level, this study expands the research dimension of the economic consequences of digital-intelligent transformation, and supplements the microeconomic evidence of drivers of ESG performance. At the practical level, the research conclusions can provide a feasible path for enterprises to improve internal control by relying on digital technology and accelerate the implementation of ESG strategies. At the same time, they can provide decision-making reference for the government and regulatory departments to formulate differentiated support policies.

Keywords

digital-intelligent transformation, ESG performance, financing constraints, internal control, instrumental variable approach

1. Introduction

At present, the digital economy has become the core engine to restructure the global economic pattern and drive deep industrial transformation [1]. The accelerated integration of digital technology and the real economy, represented by big data, artificial intelligence, cloud computing, etc., has made digital-intelligent transformation a common strategic choice for enterprises in various countries to cope with external uncertainty and pursue long-term core competitiveness. Against the background of the continuous deepening of global consensus on sustainable development, environmental, social and governance (ESG) performance has become the core benchmark to measure the level of high-quality development, international market competitiveness

and social responsibility of enterprises. In the process of domestic development, the “15th Five-Year Plan” clearly takes the construction of a digital China as an important strategic task, and proposes to further promote the deep integration of the digital economy and the real economy, and take digital-intelligent transformation as the key to cultivating new-quality productive forces and promoting industrial transformation and upgrading. Against this background, Chinese enterprises simultaneously promote the whole chain digital-intelligent layout and ESG system construction. Digital technology has gradually penetrated into production, operation, service and other links, and ESG construction has gradually shifted from compliance-oriented to value creation, which shows that digital intelligence empowers ESG promotion has become an important path for enterprises to explore high-quality development.

However, at present, the ESG performance of Chinese enterprises as a whole is still in a stage of development, generally facing real dilemmas such as insufficient endogenous motivation for green transformation, fragmentation of social responsibility implementation, and low degree of internal control digitalization. Some enterprises also have irregular ESG information disclosure and other irregularities, which greatly affects the systematic improvement of ESG comprehensive performance. Against this realistic background, whether digital-intelligent transformation can become an important driving force to solve the dilemma of enterprise ESG performance with the advantages of technological empowerment, and its specific impact and effect path still need to be verified through rigorous empirical research.

The existing literature has carried out rich research on the economic effects of digital-intelligent transformation. With the continuous deepening of the issue of sustainable development, some scholars began to pay attention to the relationship between digital-intelligent transformation and the ESG performance of enterprises. Based on the empirical test of the panel data of Shanghai-Shenzhen A-share manufacturing enterprises, it was found that digital-intelligent transformation has a significant positive promotion effect on the ESG performance of enterprises [2]; The research on power enterprises has also verified the positive effect of digital-intelligent transformation on ESG performance [3]. However, in general, the relevant research is still in its infancy, and there are still obvious research shortcomings in three aspects: First, there are limitations in the research perspective. The existing results focus on the impact of digital-intelligent transformation on the green performance of the environment (E) dimension, and lack of attention to the synergy effects such as the protection of employee rights and interests and the fulfillment of social responsibility in the social (S) dimension; Second, the mechanism analysis is not in-depth enough. Most studies are at the level of overall effect verification. The specific transmission path of digital-intelligent transformation affecting ESG performance and internal logic lack systematic and in-depth disassembly, and the “black box of the mechanism” between the two has not been fully opened; Third, the analysis of heterogeneity is not sufficient. The existing research is mainly based on overall sample regression. It is insufficient to explore the differences in effects under the nature of different property rights, regional distribution and industry characteristics, and it is difficult to provide accurate experience support for the differentiation practice of enterprises under different scenarios.

In response to the above research gaps, this paper selects China’s A-share listed companies from 2015 to 2024 as research samples to empirically test the impact effect and mechanism of digital-intelligent transformation on the ESG performance of enterprises. The marginal contribution of this study is mainly reflected in the following three points: First, from the perspective of research, this study closely combines the digital-intelligent transformation of enterprises with the comprehensive performance of ESG, systematically explains the intrinsic logical relationship between the two, breaks through the limitations of previous studies that focus on green performance in the environmental dimension, and enriches the relevant research on the value effect of digital-intelligent transformation and ESG drivers. Second, in terms of mechanism analysis, the transmission mechanism is deeply disassembled from the three paths of resource allocation efficiency, stakeholder governance and green technology innovation, and the internal logic of the ESG improvement of digital-intelligent transformation empowering enterprises is clarified, and the black box of the mechanism between the two is opened. Third, in the research dimension, the heterogeneity analysis is carried out from multiple dimensions such as the nature of enterprise property rights, region, industry attributes, etc., to identify the differences in the impact of digital-intelligent transformation on ESG performance under different scenarios, and to provide decision-making reference for different types of enterprises to accurately promote digital-intelligent transformation and optimize ESG performances.

2. Theoretical Analysis and Research Hypotheses

2.1 Digital-Intelligent Transformation and ESG Performance

Existing research has confirmed that digital-intelligent transformation has a significant effect on the total factor productivity (TFP), operational resilience and innovation ability of enterprises, but the mechanism of its role on the sustainable development performance of enterprises still needs to be systematically clarified. Digital-intelligent transformation is not a single technical upgrade, but can be embedded in the whole process operation of the enterprise through multiple transmission paths, thus providing endogenous driving force for ESG performance improvement. The intrinsic relationship between the two can be analyzed from the following perspectives.

From the perspective of resource allocation efficiency, digital-intelligent transformation relies on digital technology to break through data barriers in all aspects of production, operation and management, which not only promotes enterprises to accurately match factor resources and reduce mismatch loss, but also helps to optimize the configuration of industrial chain supply networks, improve collaborative efficiency [4], and effectively improve the overall resource allocation efficiency of enterprises [5]. On the one hand, the improvement of resource allocation efficiency can release more slack resources, so that enterprises have sufficient funds and manpower to invest in ESG-related fields such as green technology transformation and social responsibility construction; On the other hand, it can improve the business performance and market reputation of the enterprise. For example, in order to maintain a good market image, the enterprise will take the initiative to strengthen social responsibility investment, and finally promote the improvement of ESG rating.

From the perspective of stakeholder governance, digital-intelligent transformation has significantly improved the transparency of the whole process of production, operation and decision-making, which has effectively alleviated the information asymmetry between stakeholders such as enterprises and investors, consumers, regulatory authorities and the public [6]. In the market environment where the concept of sustainable development is constantly deepening, stakeholders' attention to environmental responsibility, social responsibility and internal control of enterprises continues to increase. The greater operational transparency brought about by digital intelligence will force enterprises to standardize business behavior and improve ESG information disclosure, and then promote the improvement of the comprehensive performance of enterprise ESG from the outside.

From the perspective of technological innovation and empowerment, digital-intelligent transformation provides data support and technical tools for enterprise green technology innovation, which can accelerate the application of development of green technologies and low-carbon production mode [7, 8]. The macro-experience evidence of China's manufacturing industry also shows that the effect of digital-intelligent transformation to promote energy conservation and carbon reduction through the path of technology empowerment will gradually emerge with the deepening of the transformation, and drive the energy consumption structure to upgrade to the direction of clean and low-carbon [9]. Green technology innovation can directly reduce the energy consumption and pollution emissions of enterprises in the production links. At the same time, the optimization of production mode brought about by technological upgrading will also drive the improvement of enterprise management processes, labor management practices, etc., simultaneously improve social responsibility and corporate governance level, and finally realize the improvement of the overall performance of ESG.

Based on this, this paper puts forward the following hypotheses:

H1: Digital-intelligent transformation can significantly promote the ESG performance of enterprises.

2.2 Digital-Intelligent Transformation, Financing Constraints, and ESG Performance

As a capital constraint commonly faced by enterprises, financing constraints are an important practical obstacle to the deepening of ESG performance of enterprises. As a result, digital-intelligent transformation may indirectly affect the ESG performance of enterprises through the intermediary channel of "financing constraints". Based on this, this section examines the impact of digital-intelligent transformation on financing constraints and the impact of financing constraints on the ESG performance of enterprises from the perspective of financing constraints.

Digital-intelligent transformation can significantly alleviate financing constraints. The reasons are as follows: First, digital-intelligent transformation can reduce the degree of information asymmetry. Digital intelligence technology promotes the online, data and transparent business processes of enterprises, effectively alleviates the information asymmetry between enterprises and financial institutions such as banks and external investors, reduces the cost of information collection and risk assessment of capital providers, and expands the possibility of enterprises obtaining external financing. Digital-intelligent transformation can suppress the risk of the enterprise supply chain through information flow, physical flows and capital flow. Among them, the smooth flow of information effectively alleviates the information asymmetry between supply and demand, and optimizes the financing environment faced by enterprises [10]. Second, digital-intelligent transformation can improve the efficiency of enterprise capital allocation. The digital intelligence system can carry out refined scheduling and real-time monitoring of the internal funds of the enterprise, thereby concentrating limited resources on high-return areas and improving the efficiency of the use of internal funds. Digital-intelligent transformation can promote the quality and efficiency of enterprises by improving the efficiency of capital allocation and other channels [11]. Third, digital-intelligent transformation releases positive business signals. Enterprises take the initiative to promote digital-intelligent transformation and convey a positive signal to the capital market that they have a long-term development strategy and the willingness to upgrade technology, which is conducive to enhancing the confidence of external investors and financial institutions and broadening external financing channels. Digital-intelligent transformation can significantly improve the business situation of enterprises, and lower internal financing constraints will further strengthen the role of digital-intelligent transformation in promoting investment activities [12].

At the same time, the alleviation of financing constraints can promote the ESG performance of enterprises. The main reason is that the relief of financing constraints can provide the necessary financial security for the ESG performance of enterprises. On the one hand, after the financing constraints are eased, the scale of disposable funds of enterprises will expand, and it can coordinate resource allocation from a longer-term strategic perspective and invest surplus funds in ESG-related fields. Existing studies have found that financing constraints will worsen the role of digital-intelligent transformation in promoting the employment of medium and low-skilled workers, but when financing constraints are relaxed, enterprises will be more inclined to protect the rights and interests of workers and fulfill their social responsibilities [13]. On the other hand, the alleviation of financing constraints can reduce the short-term performance pressure of enterprises, make enterprises pay more attention to long-term sustainable development goals, take the initiative to strengthen environmental governance investment, improve internal control mechanisms, and improve the quality of ESG information disclosure, so as to promote the improvement of enterprise ESG performance in an all-round way.

Based on this, this paper puts forward the following hypotheses:

H2: Digital-intelligent transformation can significantly promote the ESG performance of enterprises by easing financing constraints.

2.3 Digital-Intelligent Transformation, Internal Control, and ESG Performance

Internal control is the institutional arrangement for enterprises to prevent risks, standardize operation and ensure information quality, and it is also the core of the corporate governance system. Digital-intelligent transformation can significantly improve the level of internal control by restructuring business processes and information transmission methods, thus providing institutional guarantee for enterprise ESG performance.

Digital-intelligent transformation can significantly strengthen internal control. Digital-intelligent transformation mainly strengthens the internal control of enterprises through three paths. First of all, the digital-intelligent system can embed control links such as authorization approval, review and verification into the business process, and promote the automation and standardized implementation of control activities, so as to reduce the risk of human intervention and operation. Then, realize the real-time communication and automatic trace of business and financial data, so that enterprises can monitor and trace the whole process of business activities, which is conducive to enhancing the timeliness of internal supervision. The financial sharing center has significantly improved the efficiency of internal supervision and risk control by relying on the integration of business and finance [14]. Third, accelerate the construction of a data-driven decision-making mechanism to promote the transparency and traceability of management decision-making, which reduces the risk of management over internal control. At the same time, the process supervision of employee behavior of the

digital intelligence system regulates the internal behavior of the organization. Digital-intelligent transformation can inhibit the destructive deviant behavior of employees, so that organizational behavior is consistent with the goal of internal control [15].

On this basis, the strengthening of internal control will also promote the ESG performance of enterprises. First, sound internal control helps enterprises identify and respond to risks at the environmental, social and business levels, and ensure the stable operation of enterprises, which provides a resource basis for enterprises to continuously invest in green transformation and social responsibility. A perfect risk control mechanism can suppress supply chain risks and equip enterprises with the conditions to invest in long-term sustainable development projects [10]. Second, internal control suppresses the tendency of management to sacrifice environmental governance and social responsibility in order to pursue short-term performance through power checks and balances and supervision constraints, and prompts enterprises to coordinate economic, social and environmental benefits from a long-term perspective. Third, good internal control not only restricts the compliant business operations of enterprises, but also protects the rights and interests of employees and other stakeholders, which provides a micro-foundation for the performance of enterprises in the dimension of social responsibility.

Based on this, this paper puts forward the following hypotheses:

H3: Digital-intelligent transformation can significantly promote the ESG performance of enterprises by improving internal control.

3. Research Design

3.1 SAMPLE Selection and Data Sources

This paper selects Chinese A-share listed companies from 2015 to 2024 as the sample to investigate the impact of digital-intelligent transformation on ESG performance. This study conducts the following preliminary data processing: (1) excluding samples from the financial industry; (2) excluding ST, *ST, and PT samples; (3) excluding samples with missing core variables; and (4) winsorizing all variables at the 1% level. The data are sourced from the CNRDS and CSMAR databases.

3.2 Variable Definitions

(1) Dependent variable: Corporate ESG performance (ESG). Drawing on the studies by Yuan Liang et al. [2] and Pang Lei et al. [16], this paper uses the Sino-Securities (CNRDS) comprehensive ESG score to measure corporate ESG performance; a higher score indicates a superior overall ESG performance. The data are sourced from the CNRDS database.

(2) Explanatory variables: Corporate digital-intelligent transformation (Dsc). Drawing on the study by Ge Lulan and Jin Hongfei [17], the degree of digital-intelligent transformation is measured based on the keyword frequency in the annual reports of listed companies (calculated as the logarithm of frequency plus one); a higher value indicates a higher level of transformation.

(3) Control variables: This paper selects the following control variables: return on assets (ROA), nature of property rights (SOE), firm size (Size), leverage (Lev), net profit margin (NetProfit), loss status (Loss), board size (Board), and duality (Dual). Specifically, Return on Assets (ROA) is measured as the ratio of net profit to total assets at the end of the period; the ownership variable (SOE) takes a value of 1 for state-owned enterprises and 0 otherwise. Firm size (Size) is the natural logarithm of total assets at year-end; the leverage (Lev) is the ratio of total liabilities to total assets at the end of the period; the net profit margin (NetProfit) is the ratio of net profit to operating income for the period; For the loss status variable (Loss), a value of 1 indicates that the firm is operating at a loss, while a value of 0 indicates profitability; board size (Board) is measured as the natural logarithm of the total number of board members for the year; and the duality variable (Dual) takes a value of 1 if the roles of board chairman and general manager are held by the same person, and 0 if the roles are separated. The data are sourced from the CSMAR database.

3.3 Model Specification

To test hypothesis H1, this paper constructs the following regression model:

$$ESG_{i,t} = \alpha_0 + \alpha_1 Dsc_{i,t} + \alpha_2 \sum Controls_{i,t} + \delta_{Year} + \gamma_{Industry} + \varepsilon_{i,t} \quad (1)$$

Here, the subscripts i and t denote the firm and the year, respectively; the dependent variable ($ESG_{i,t}$) (“ESG performance”) represents the ESG rating of firm i in year t ; the core explanatory variable ($Dsc_{i,t}$) (“digital-intelligent transformation”) represents the level of digital-intelligent transformation of firm i in year t ; Controls represents a set of control variables; δ_{Year} and $\gamma_{Industry}$ represent year fixed effects and industry fixed effects, respectively; and $\varepsilon_{i,t}$ is the random error term.

To test hypotheses H2 and H3, this paper constructs the following regression model:

$$Median_{i,t} = \alpha_0 + \alpha_1 Dsc_{i,t} + \alpha_2 \sum Controls_{i,t} + \delta_{Year} + \gamma_{Industry} + \varepsilon_{i,t} \quad (2)$$

Among them, the mechanism variable $Median_{i,t}$ represents “financing constraints” and “internal control”, while the remaining variables follow Model (1).

4. Empirical Results and Analysis

4.1 Descriptive Statistics

Table 1 is the descriptive statistics of this study. The average value of the dependent variable ESG performance (ESG) is 4.1845, the standard deviation is 0.8842, the minimum value is 1.7500, and the maximum value is 6.5000, which shows that there is a certain difference in the ESG performance of the enterprise, but the observations are generally concentrated at the upper-middle level. The mean value of the core explanatory variable enterprise digital-intelligent transformation (Dsc) is 1.7467, the standard deviation is 1.4116, the minimum value is 0, and the maximum value is 5.1591, which shows that there is considerable variation in the degree of digital-intelligent transformation of different enterprises, and some enterprises have not carried out digital-intelligent transformation.

Table 1: Descriptive Statistics

Variable	N	Min	Max	Mean	p50	SD
ESG	21626	1.7500	6.5000	4.1860	4	0.8850
Dsc	21626	0	5.1590	1.7470	1.6090	1.4120
ROA	21626	-0.2320	0.1870	0.0321	0.0352	0.0640
SOE	21626	0	1	0.2930	0	0.4550
Size	21626	19.8600	26.4700	22.2600	22.0100	1.3410
Lev	21626	0.0540	0.8870	0.4020	0.3910	0.2010
NetProfit	21626	-0.9380	0.4770	0.0558	0.0701	0.1940
Loss	21626	0	1	0.1160	0	0.3200
Board	21626	1.6090	2.7080	2.0940	2.1970	0.2000
Dual	21626	0	1	0.3390	0	0.4730

4.2 Correlation Analysis

Table 2 is the correlation test of this study. The correlation coefficient between the dependent variable, ESG performance (ESG), and the core explanatory variable, digital-intelligent transformation (Dsc), is 0.167 and is significantly positive at the 1% level. It preliminarily shows that the higher the ESG performance level of the enterprise, the higher the degree of digital-intelligent transformation, which initially supports the research hypothesis H1.

4.3 Baseline Regression Results

Table 3 shows the test results of the baseline regression model in this paper. Table 3 column (1) is the regression result of the enterprise digital-intelligent transformation (Dsc) that only includes the core explanatory variable. From here, we can see that the enterprise digital-intelligent transformation coefficient is 0.1060, which has a positive effect on the ESG performance of enterprises at a significance level of 1%.

Column (2) of Table 3 further introduces a series of firm-level control variables while controlling for year and industry fixed effects; the regression results show that the coefficient for corporate digital-intelligent transformation is 0.0950, indicating a significant positive impact on corporate ESG performance at the 1% level. The above results show that digital-intelligent transformation of enterprises can significantly improve the ESG performance of enterprises. Digital-intelligent transformation promotes the optimization of the operation mode of enterprises, strengthens the level of enterprise information disclosure, brings closer communication between enterprises and investors, employees, the public and other stakeholders, forces enterprises to pay attention to environmental responsibility, social responsibility and internal control construction, and effectively improves the ESG performance of enterprises. Therefore, Hypothesis H1 is supported.

Table 2: Correlation Test

	ESG	Dsc	ROA	SOE	Size	Lev	NetProfit	Loss	Board	Dual
ESG	1									
Dsc	0.167***	1								
ROA	0.207***	-0.089***	1							
SOE	0.034***	-0.136***	-0.053***	1						
Size	0.236***	-0.033***	0.055***	0.409***	1					
Lev	-0.113***	-0.061***	-0.314***	0.284***	0.491***	1				
NetProfit	0.177***	-0.087***	0.849***	-0.00900	0.069***	-0.268***	1			
Loss	-0.193***	0.059***	-0.387***	0.014**	-0.081***	0.149***	-0.369***	1		
Board	0.023***	-0.079***	0.027***	0.292***	0.304***	0.153***	0.037***	-0.039***	1	
Dual	0.003	0.088***	-0.003	-0.327***	-0.226***	-0.141***	-0.012*	0.019***	-0.198***	1

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3: Baseline Regression

	(1)	(2)
VARIABLES	ESG	ESG
Dsc	0.1057*** (21.6021)	0.0948*** (20.8897)
ROA		1.5579*** (9.3592)
SOE		0.0366*** (2.5810)
Size		0.2423*** (45.1928)
Lev		-0.9677*** (-27.8605)
NetProfit		-0.0930* (-1.7449)
Loss		-0.2977*** (-16.0986)
Board		-0.1468*** (-5.0558)
Dual		0.0523*** (4.3095)
Constant	3.9399*** (149.3017)	-0.7483*** (-6.3093)
Observations	21,626	21,626
R-squared	0.064	0.212
Adj. R2	0.210	0.210

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively; values in parentheses are t-values. The same applies below.

4.4 Mechanism Analysis

In order to clarify the intrinsic path of the digital-intelligent transformation of enterprises affecting the ESG performance of enterprises, this study selects financing constraints and internal control as mechanism variables to carry out mechanism analysis. In terms of the financing constraints of the digital-intelligent transformation of enterprises, this study obtains data from the CSMAR database and uses the absolute value of the SA index to measure it; As for the internal control mechanism variables of the digital-intelligent transformation of enterprises, this paper obtains the internal control index and rating of the enterprise through the internal control

and risk management database of Dibo, and uses the internal control index (IC) as a proxy variable. The specific test results are shown in Table 4. Column (1) reports the baseline regression results of digital-intelligent transformation on the ESG performance of enterprises. The coefficient of enterprise digital-intelligent transformation (Dsc) is 0.0948, and it is significantly positive at the level of 1%, which shows that enterprise digital-intelligent transformation can significantly improve the ESG performance of enterprises, that is, enterprise digital-intelligent transformation has a significant positive effect on enterprise ESG performance, which lays the foundation for the subsequent impact mechanism test. Column (2) shows that the digital-intelligent transformation of enterprises has a strong inhibitory effect on the financing constraints of enterprises, which shows that the digital-intelligent transformation of enterprises can provide more operating and management funds for enterprises by suppressing financing constraints, thus improving the ESG performance of enterprises. That is, the research in this study assumes that H2 is established. Column (3) shows that the digital-intelligent transformation of enterprises has significantly promoted the internal control of enterprises, which shows that the digital-intelligent transformation of enterprises promotes the internal control of enterprises, thereby promoting enterprises to assume environmental responsibilities, and ultimately improving corporate ESG performance, that is, the research in this study assumes that H3 is established.

Table 4: Test of influence mechanisms

VARIABLES	(1) ESG	(2) SA	(3) IC
Dsc	0.0948*** (20.8897)	-0.0045*** (-3.0787)	0.0162*** (3.1277)
ROA	1.5579*** (9.3592)	0.1025* (1.9112)	1.7729*** (9.3248)
SOE	0.0366*** (2.5810)	0.0791*** (17.3437)	0.0495*** (3.0592)
Size	0.2423*** (45.1928)	-0.0406*** (-23.5070)	0.0505*** (8.2533)
Lev	-0.9677*** (-27.8605)	0.1253*** (11.2022)	-0.2374*** (-5.9841)
NetProfit	-0.0930* (-1.7449)	0.0168 (0.9784)	0.4269*** (7.0151)
Loss	-0.2977*** (-16.0986)	0.0101* (1.6974)	-0.1015*** (-4.8065)
Board	-0.1468*** (-5.0558)	0.0838*** (8.9548)	-0.0433 (-1.3059)
Dual	0.0523*** (4.3095)	-0.0430*** (-10.9948)	0.0627*** (4.5220)
Constant	-0.7483*** (-6.3093)	4.4085*** (115.3831)	5.2027*** (38.4057)
Observations	21,626	21,626	21,626
R-squared	0.212	0.135	0.065
Adj. R2	0.0639	0.0639	0.0639

4.5 Endogeneity Tests

4.5.1 Propensity Score Matching (PSM)

Because the level of enterprise digital-intelligent transformation (Dsc) may not be randomly distributed, but affected by the characteristics of the enterprise itself, and there may be sample self-selection bias in the direct baseline regression. Therefore, this study builds a framework through the propensity score matching method (PSM) to match the control group enterprises with similar characteristics but low Dsc level for the treatment group (high Dsc enterprises), so as to more accurately identify the impact of enterprise digital-intelligent transformation (Dsc) on the ESG performance of enterprises.

First of all, the propensity score is measured. This paper takes the binary virtual variable high Dsc enterprise (high_Dsc) as the dependent variable, incorporates the various characteristic indicators of the enterprise to build a Logit model, and measures the propensity score of the sample; Secondly, carry out sample matching. Relying on the propensity score, choose the 1:1 nearest neighbor matching strategy to match the sample of the control group for the treatment group sample, and only retain the observation values in the common support

interval; Then carry out the equilibrium test. After matching, the inter-group deviation of each covariate group is significantly reduced, and the difference between the group is not significant, which meets the PSM equilibrium hypothesis. Finally, the core effect is re-evaluated, and the regression test is carried out again based on the successfully matched samples to obtain purer empirical results.

The regression results based on the matching sample are shown in Table 5. The regression coefficient of enterprise digital-intelligent transformation (Dsc) is 0.0917, which passes the significance test at the 1% level and the symbol is positive. This means that after alleviating the estimation bias caused by the sample self-selection problem, the positive improvement effect of enterprise digital-intelligent transformation (Dsc) on the ESG performance of enterprises is still significant, which is mutually confirmed with the baseline regression conclusion, fully showing that the core research conclusion of this study is robust.

4.5.2 Instrumental Variable Approach

The empirical testing process of this study may have endogenous problems caused by mutual causality, that is, the digital-intelligent transformation of enterprises will affect the ESG performance of enterprises, and enterprises with good ESG performance will also be more inclined to improve their own level of digital-intelligent transformation. This paper uses two sets of instrumental variables combined with the two-stage least squares method (2SLS) to deal with possible reverse causal problems.

(1) Lagged by one period

First of all, choose the lagging digital-intelligent transformation level (LDsc) as a tool variable. The core logic is: First, the digital-intelligent transformation of enterprises has strong path dependence characteristics, and the digital-intelligent transformation level of the previous period is highly related to the current level; Second, the ESG performance of the current enterprise cannot reversely affect the decision-making of the digital-intelligent transformation of the previous period, which can effectively weaken the estimated bias caused by the two-way cause and effect.

In the specific operation, this paper generates the lag phase one-phase variable (LDsc) of the core explanatory variable as a tool variable, and constructs a two-stage least squares model, while incorporating all benchmark control variables and year fixed effects. The regression results are shown in Table 5: Column (2) is the regression result of the first stage. The regression coefficient of the instrumental variable (LDsc) is 0.9014, which is significantly positive at the statistical level of 1%, indicating that the instrumental variable is highly correlated with endogenous variables and has a strong explanatory power for endogenous variables. Column (3) is the regression result of the second stage. The coefficient of the core explanatory variable (Dsc) is 0.1258, which also significantly affects the ESG performance of the enterprise at the level of 1%.

(2) Alternative Instrumental Variable

Secondly, this paper further constructs the median (medianDsc) of the level of digital-intelligent transformation as the second set of instrumental variables to verify the reliability of the conclusion under the dimensions of the same year, the same province and the same industry. The overall atmosphere of digital-intelligent transformation in the same province and the same industry will affect the digital-intelligent transformation of individual enterprises through technology spillover, industry competition and other paths, which meets the relevance requirements of instrumental variables; The median level at the provincial level of the industry is jointly determined by the group. It will not directly affect the ESG performance of a single enterprise, and it is difficult to be adversely affected by a single enterprise, which has an exogenous basis.

In the specific operation, this study groups the samples according to the three dimensions of year, province and industry, calculates the median of Dsc in the group as a tool variable (medianDsc), and carries out the two-stage least squares regression again. The regression results are shown in Table 5: Column (4) is the regression result of the first stage. The regression coefficient of the instrumental variable (medianDsc) is 0.8502, which is significantly positive at the statistical level of 1%, indicating that the instrumental variable is highly correlated with endogenous variables and has a strong explanatory power for endogenous variables. Column (5) presents the results of the second-stage regression; the coefficient of the core explanatory variable (Dsc) is 0.1469, indicating a significant impact on corporate ESG performance at the 1% level.

In summary, the regression results of the two sets of instrumental variables with different settings show that after trying to eliminate endogenous interference, the positive impact of digital-intelligent transformation

on the ESG performance of enterprises has always been significantly positive, and the coefficient direction is consistent with the baseline regression, which fully proves that the baseline regression results of this study have good robustness.

Table 5: Endogeneity Tests

VARIABLES	(1) PSM ESG	(2) first Dsc	(3) second ESG	(4) first Dsc	(5) second ESG
Dsc	0.0917*** (19.3391)		0.1258*** (25.5679)		0.1469*** (21.3832)
LDsc		0.9014*** (272.6865)			
medianDsc				0.8502*** (103.3641)	
ROA	1.6386*** (9.3149)	0.0372 (0.2677)	1.4940*** (8.0003)	-0.4038* (-1.7233)	1.6896*** (10.1385)
SOE	0.0478*** (3.1147)	-0.0450*** (-3.9167)	0.0179 (1.1604)	-0.2689*** (-13.7153)	0.0296** (2.0921)
Size	0.2304*** (38.4734)	0.0046 (1.0382)	0.2437*** (41.3477)	0.1084*** (14.7338)	0.2295*** (43.5617)
Lev	-0.9231*** (-25.0544)	-0.0475* (-1.6566)	-1.0058*** (-26.1422)	-0.1522*** (-3.1538)	-0.9413*** (-27.3510)
NetProfit	-0.1085* (-1.9060)	-0.0166 (-0.3723)	-0.1048* (-1.7474)	-0.2337*** (-3.1145)	-0.1212** (-2.2743)
Loss	-0.2869*** (-14.7406)	-0.0090 (-0.5966)	-0.3033*** (-15.0215)	0.0347 (1.3161)	-0.3081*** (-16.4416)
Board	-0.1588*** (-5.1886)	-0.0191 (-0.7789)	-0.1546*** (-4.6878)	-0.1087*** (-2.6387)	-0.1574*** (-5.3721)
Dual	0.0458*** (3.5921)	0.0336*** (3.2507)	0.0495*** (3.5684)	0.0392** (2.2663)	0.0512*** (4.1619)
Constant	-0.4826*** (-3.6562)	0.3065*** (3.1637)	-0.8336*** (-6.4089)	-1.6345*** (-9.9135)	-0.5279*** (-4.5320)
Observations	19,296	17,429	17,429	21,626	21,626
R-squared	0.198	0.820	0.200	0.367	0.187
Adj. R2	0.197	0.820	0.200	0.366	0.186

4.6 Robustness Tests

4.6.1 Additional Control Variables

Considering that the missing variables will affect the empirical results, this paper will include three additional variables that are not in the set of baseline regression control variables, namely capital intensity (CAP), the shareholding ratio of the largest shareholder in equity concentration (TOP1) and the book market value ratio (BM), and re-regress the regression test. Column (1) of Table 6 presents the regression results after incorporating these three control variables. As shown in the table, the regression results regarding the relationship between digital-intelligent transformation and corporate ESG performance remain substantially unchanged compared to the baseline regression, indicating that the conclusions are robust.

4.6.2 Alternative Fixed Effects Specifications

Due to the differentiated local support policies and environmental supervision rules introduced by different regions, there are also significant differences in the market level and resource endowment of each province. If we only control the fixed effect of the industry and the year, we can only capture the characteristics of the industry that do not change over time and the common time shock at the national level, but we cannot fully absorb the unique macro-environmental interference of each province every year. Therefore, the joint fixed effect of the provincial year is introduced to control the unobservable factors that change over time at the regional level. (2) in Table 6 is listed as the regression result of replacing the fixed effect. The coefficient direction and significance of the core explanation variable are basically consistent with the baseline regression results, which shows that the research conclusion is stable and reliable.

4.6.3 Robust Standard Errors

There is often a correlation between the observation samples of different years of the same enterprise. For example, the influence of external shocks on the enterprise will usually continue for multiple accounting years, which will cause the model disturbance items to have within-group self-correlation; There is a large gap in the business scale of different enterprises, and it is also prone to the problem of variance. Based on this, this study will make cluster adjustments at the enterprise level by clustering standard errors at the firm level, so as to alleviate the statistical inference bias caused by the variance and the internal timing self-correlation of the enterprise. Judging from the regression results of column (3) in Table 6, the results are highly consistent with the baseline regression results, which further proves that the core research conclusions of this study are robust.

Table 6: Robustness Tests

VARIABLES	(1) Add control variables	(2) Change fixed effects	(3) Consider robust standard errors
	ESG	ESG	ESG
Dsc	0.0940*** (20.6187)	0.0972*** (24.2517)	0.0948*** (12.5078)
ROA	1.3345*** (7.8107)	1.5878*** (9.6434)	1.5579*** (6.6518)
SOE	0.0253* (1.7471)	0.0479*** (3.3792)	0.0366 (1.4133)
Size	0.2520*** (42.2572)	0.2328*** (44.3096)	0.2423*** (23.7162)
Lev	-0.9639*** (-27.7335)	-0.9426*** (-27.6814)	-0.9677*** (-16.2475)
NetProfit	-0.0673 (-1.2563)	-0.1243** (-2.3603)	-0.0930 (-1.2587)
Loss	-0.2987*** (-16.1011)	-0.2941*** (-15.8885)	-0.2977*** (-14.7811)
Board	-0.1375*** (-4.7186)	-0.1271*** (-4.3653)	-0.1468*** (-2.9159)
Dual	0.0497*** (4.0970)	0.0375*** (3.0728)	0.0523*** (2.7956)
CAP	-0.0002 (-0.8004)		
Top1	0.1748*** (4.4512)		
BM	-0.1266*** (-4.5180)		
Constant	-0.9785*** (-7.7128)	-0.5840*** (-5.0088)	-0.7483*** (-3.3406)
Observations	21,625	21,626	21,626
R-squared	0.213	0.210	0.212
Adj. R2	0.210	0.210	0.210

4.7 Heterogeneity Analysis

There are significant differences in the impact of enterprises with different characteristics on the level of digital-intelligent transformation on the ESG performance of enterprises. For this reason, this study groups sample enterprises and carries out heterogeneity analysis from the nature of property rights, geographical location, technical attributes and other dimensions of enterprises, and considers the differentiated impact of the digital-intelligent transformation of enterprises on the ESG performance of enterprises.

4.7.1 Heterogeneity by Ownership Structure

The sample is divided into two groups—“state-owned enterprises” and “non-state-owned enterprises”—based on the nature of property rights for grouped regression analysis; the results are presented in columns (1) and (2) of Table 7. Although the regression coefficients for the digital-intelligent transformation of enterprises in both the “state-owned enterprise” and “non-state-owned enterprise” groups are significantly positive, the Chow test statistic is 9.72—passing the significance test at the 1% level—which demonstrates a significant

difference between the regression coefficients of the two groups. The results indicate that the ESG promoting effect of digital-intelligent transformation is more pronounced in non-state-owned enterprises.

4.7.2 Heterogeneity by Geographic Location

In this study, the sample is divided into two subsamples—“Northern enterprises” and “Southern enterprises”—based on the location of corporate registration, and regression analyses are conducted for each; the empirical results are presented in columns (3) and (4) of Table 7. The regression coefficients for digital-intelligent transformation of enterprises in both the “Northern Enterprises” and “Southern Enterprises” groups were significantly positive. Further testing of the differences in coefficients between groups yielded a Chow test statistic of 5.26, which is significant at the 1% statistical level. This indicates that, although the digital-intelligent transformation of enterprises plays a positive role in both types of regions, the intensity of this driving effect differs significantly between enterprises in the South and the North.

4.7.3 Heterogeneity by Technological Attributes

In this study, the sample is divided into two subsamples—“high-tech enterprises” and “non-high-tech enterprises”—based on the technological attributes of the firms. Regression analyses are conducted separately for each subsample, and the results are presented in columns (5) and (6) of Table 7. The regression coefficients for digital-intelligent transformation of enterprises in both the “high-tech enterprise” group and the “non-high-tech enterprise” group were significantly positive. Further testing of the differences in coefficients between the groups yielded a Chow test statistic of 14.14, which is significant at the 1% statistical level. The findings indicate that digital-intelligent transformation positively enhances the ESG performance of both types of enterprises; however, the extent of this impact varies significantly, with “high-tech” enterprises benefiting more from this enabling effect than “non-high-tech” enterprises.

Table 7: Heterogeneity analysis

VARIABLES	(1) State- owned ESG	(2) Non-state- owned ESG	(3) Northern ESG	(4) Southern ESG	(5) High-tech ESG	(6) Non-high-tech ESG
Dsc	0.0965*** (9.6196)	0.0978*** (19.4677)	0.1062*** (12.1986)	0.0901*** (16.9309)	0.1080*** (20.6638)	0.0588*** (6.5982)
ROA	0.1561 (0.4438)	2.0866*** (11.1263)	1.0985*** (3.4420)	1.6526*** (8.4526)	2.0677*** (9.7259)	1.1592*** (4.2206)
SOE			0.0541** (2.2571)	0.0574*** (3.2108)	-0.0081 (-0.4369)	0.0872*** (3.9378)
Size	0.2903*** (32.1316)	0.2136*** (31.3161)	0.2632*** (28.6177)	0.2356*** (35.0881)	0.2266*** (33.2624)	0.2620*** (30.1721)
Lev	-1.2094*** (-17.3670)	-0.8706*** (-21.7007)	-1.1918*** (-18.8523)	-0.8804*** (-21.0385)	-1.0032*** (-23.6913)	-0.8389*** (-14.0046)
NetProfit	0.2839*** (2.6082)	-0.2402*** (-3.9759)	-0.1048 (-1.0949)	-0.0540 (-0.8362)	-0.2816*** (-3.9775)	0.0590 (0.7275)
Loss	-0.2950*** (-8.3962)	-0.2952*** (-13.6861)	-0.2737*** (-8.2580)	-0.3020*** (-13.5945)	-0.2966*** (-13.2342)	-0.3136*** (-9.7786)
Board	-0.1608*** (-2.7280)	-0.1225*** (-3.6974)	-0.0354 (-0.6621)	-0.1763*** (-5.0930)	-0.0784** (-2.2181)	-0.2538*** (-5.0677)
Dual	0.0109 (0.3068)	0.0469*** (3.7082)	0.0543** (2.2178)	0.0398*** (2.8549)	0.0441*** (3.1299)	0.0396* (1.7141)
Constant	-1.5720*** (-7.2885)	-0.2852* (-1.9282)	-1.3814*** (-6.5871)	-0.5684*** (-3.8831)	-0.5422*** (-3.6102)	-1.0183*** (-5.2512)
Test Statistic	9.72***		5.26***		14.14***	
Observations	6,329	15,297	6,449	15,177	13,877	7,749
R-squared	0.270	0.197	0.243	0.207	0.199	0.251
Adj. R2	0.222	0.222	0.222	0.222	0.248	0.248

5. Conclusions and Implications

Based on the sample of China’s A-share listed companies from 2015 to 2024, this paper conducts a multi-dimensional empirical analysis of the relationship between digital-intelligent transformation and corporate

ESG performance. The empirical results show that the digital-intelligent transformation of enterprises can significantly improve their own ESG performance, and after endogeneity tests and robustness tests, the positive promotion effect is still stable. At the same time, digital-intelligent transformation can indirectly improve ESG performance by alleviating the financing constraints of enterprises and improving the quality of internal control, both of which have played a significant intermediary role in the transmission process. Further research has found that the promotion effect is obviously differentiated in enterprises with different characteristics. In the sample of non-state-owned enterprises, enterprises in the northern region and high-tech enterprises, the positive driving effect of digital-intelligent transformation on ESG performance is stronger.

Based on the above conclusions, this study puts forward the following policy implications:

(1) Digital-intelligent transformation is the core driving force for improving ESG performance.

Digital-intelligent transformation is an important path for enterprises to improve their sustainable development ability. Enterprises should take the initiative to conform to the trend of digital economy, accelerate the integration and application of digital technology in the whole process of production, governance and information disclosure, and drive the improvement of ESG performance with technological innovation, and then transform digital intelligence capabilities into sustainable competitive advantages to achieve the coordinated growth of economic benefits and social values.

(2) Broaden the financing channels for enterprises

Financing constraints are the key factors that restrict enterprises' ESG investment. The government can work with financial institutions to establish a digital-intelligent transformation credit assessment system in order to provide interest rate discount or guarantee support to enterprises with large investment and good results in transformation; At the same time, it can also encourage enterprises to enhance information disclosure through digital platforms, reduce information asymmetry with the funder, and directly transform it into financing advantages.

(3) Strengthen the construction of internal control

Internal control is the institutional carrier for the implementation of ESG strategy. Enterprises should use digital technology to reconstruct the internal control process to realize real-time risk monitoring and decision-making trace; The regulatory authority can include the degree of digitalization of internal control of enterprises in the plus points of ESG rating to guide enterprises to improve the level of ESG from the basis of internal control.

(4) Implement accurate and differentiated assistance policies

In view of the differences in the transformation foundation and development conditions of different types of enterprises, classification policies and accurate support should be given. State-owned enterprises and high-tech enterprises have more transformation dividends due to the advantages of organizational foundation and technical capabilities, which suggests that non-state-owned enterprises and traditional cultural enterprises need to pay more attention to the accumulation of basic conditions before transformation; The stronger effect of northern enterprises shows that in areas with relatively weak digital infrastructure, there is more room for marginal improvement, so pouring more policy resources may produce higher social returns.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

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