

Research on the Nonlinear Effect of Digital Transformation Rate on Enterprise ESG Performance

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Abstract

ESG is a key factor driving enterprise sustainability and a core indicator of long-term business value and social responsibility. In the digital economy, it is meaningful to discuss the relationship between the rate of digital transformation and enterprise ESG performance. This paper takes A-share listed companies in Shanghai and Shenzhen from 2010 to 2023 as samples, and adopts an empirical research method, and finds that the relationship between the rate of digital transformation and the ESG performance of enterprises is "inverted U-shape". The study also points out that green innovation is a mechanism that has a more salient effect on non-state-owned companies, high-tech firms and enterprises in the eastern region.

Keywords

Digital Transformation Rate; ESG; Green Innovation; Inverted U-shaped.

1. Introduction and Literature Review

The ESG concept is developed from corporate social responsibility (CSR). It refers to the comprehensive performance of enterprises in three aspects: environment, society and governance. It is an important standard for modern enterprises to evaluate their long-term value and sustainable development.[1]. In order to encourage enterprises to actively practice the ESG concept, China has successively issued a number of documents, such as Guidelines for the Publication of Corporate Social Responsibility Reports, Guidelines for the Preparation of China's Corporate Sustainability Reports, and Guidelines for Disclosure of ESG Information in China's Securities Market, etc. This shows that our government has gradually incorporated ESG-related policies into the capital market regulatory framework. Existing research suggests that strengthening environmental, social and corporate governance practices not only enhances enterprise reputation and brand value and increases investor trust and attractiveness, promotes improvements in internal governance and business efficiency [2], but also helps businesses identify and overcome potential social and environmental risks, better respond to external regulation and to promote sustainable development. [3], so how to improve the level of corporate ESG has been widely concerned by the society.

Studies reveal that digital transformation has gradually become a central strategy for businesses to drive up economic growth, improve competitiveness and tackle various challenges in the marketplace.[4] On the one hand, digital transformation opens up new business models and facilitates the development of sharing platforms and the sharing economy[5], enterprises make use of the sharing platform to improve their learning ability, enhance their innovation ability, optimize resource allocation through the application of digital technology, boost work output efficiency, rapidly correspond to market variations, and upgrade competitiveness in the marketplace; On the other hand, digitalization has changed people's way of life, and the popularization of digital technology has greatly improved the convenience and efficiency of life, boosted the industrial structure optimization and upgrading[6], driven the

green transformation, and laid the groundwork for businesses to exercise the concept of ESG and high-quality development.

Currently, most scholars suggest that digital transformation can increase ESG performance by raising efficiency[7], easing financing restraints, and decreasing financial risks[8]; a few researchers think that there is an “inverted U-shape” relationship between digital transformation and business ESG performance, and that suitable digital transformation can enhance ESG performance, but excessive digital transformation will crowd out ESG investment and reduce ESG performance[9].

To summarize, the conclusions of existing studies on digital transformation on ESG performance are inconsistent, but most scholars support the “facilitation theory”. This paper believes that the impact of digital transformation on ESG performance should not be viewed only from the aspect of the degree of digital transformation, overlooking the dynamic impact of the speed of firms' digital transformation. Therefore, this paper discusses the impact of the speed of digital transformation on the ESG performance of enterprises using the data of A-share listed companies in Shanghai and Shenzhen from 2010 to 2023, and the mediator variable of green innovation is introduced for empirical testing. The contributions of this paper's boundaries are: first, most scholars currently focus on the impact of the degree of digital transformation on firms' ESG performance and do not pay attention to the influence of the dynamic rate of digital transformation on enterprises' ESG performance; second, most of the existing studies have explored the positive impact of digital transformation on firms' ESG performance, while disregarding the negative effects of too fast a rate of digital transformation on the firms; third, this paper introduces green innovation explores the mechanism by which digital transformation rate affects ESG performance; fourth, this paper analyzes the heterogeneity of enterprise ownership, industry specificity and geographic location, which provides a reference to maintain a reasonable transformation rate for the digital transformation of enterprises in China.

2. Theoretical Analysis and Research Hypothesis

2.1. Analysis of the ' Inverted U-shaped ' Impact of Digital Transformation Rate on Enterprise ESG Performance

First, analyzing the pre-facilitation stage, this paper argues that increased transformation rate can bring advanced digital technology to enterprises, which significantly improves resource allocation efficiency, operation and management capabilities and social responsibility fulfillment, thus improving their ESG performance. With the deepening of digital transformation, enterprises gradually increase their investment in technology and innovation, reduce information asymmetry, improve transparency between shareholders and management, enhance external monitoring capabilities, and optimize the level of management decision-making. In this way, firms are able to realize cost reduction and efficiency gains in a shorter period of time and have more resources to spend on improving their ESG performance.

Second, analyzing the late inhibition stage, based on the theory of time compression diseconomies and finite theory, if the transformation rate is too fast, it may neglect the management of social responsibility and governance risks due to over-reliance on technology, which will lead to a decline in ESG performance. Too fast transformation makes companies focus too much on the improvement of technological efficiency and neglect the investment in social responsibility areas such as employee welfare and community benefits. In addition, rapid transformation may make the corporate governance structure inadequate and lack the necessary laws, regulations and ethical norms to regulate the application of technology, leading to the inability of enterprises to effectively balance the increasing rate of transformation with their limited resources and capabilities. This situation makes it difficult for enterprises to

optimize resource allocation and cost control, ultimately leading to a decline in ESG performance.

This leads to hypothesis H1 of this paper:

H1 : There is an “inverted U-shaped” relationship between the rate of digital transformation and an organization's ESG performance

2.2. Analysis of the Intermediary Effect of Green Technology Innovation

When enterprises accelerate the rate of digital transformation, they become more skillful and flexible in the use of the Internet and digital technology, which helps to reduce the transaction cost of acquiring external knowledge, and at the same time enables them to obtain information such as market trends and customer needs more quickly, promotes the greening process of the traditional manufacturing processes and equipment, and provides a more solid foundation for the development of green technological innovation, which in turn enhances their green innovation ability of enterprises. Enhanced green technological innovation helps enterprises reallocate resources and environmental factors, optimize industrial structure, reduce the level of non-efficient investment, and develop more environmentally friendly and consumer-friendly products. By enhancing green innovation capability, enterprises not only strengthen market competitiveness, but also improve ESG performance.

However, as the rate of digital transformation continues to accelerate, an enterprise's resource base and capabilities may not be able to keep up with the demands of high-speed transformation, leading to a gradual decline in green technology innovation capabilities. When the rate of transformation is too fast, although enterprises can access a large amount of information in a short period of time, they tend to focus too much on improving short-term operational efficiency, concentrating their resources on rapid technology iteration and market response, while neglecting the development of environmentally friendly technologies and the innovation of green products. This tilting of resources may crowd out resources and planning for green innovation, neglect corporate social responsibility, and ultimately lead to a decline in ESG performance.

Therefore, when the rate of digital transformation is within a certain range, the green innovation ability of enterprises can be effectively improved, and the ESG performance of enterprises will also be improved; however, too fast a rate of digital transformation will have an inhibitory effect on the level of green innovation of enterprises, and this inhibitory effect will lead to a decrease in the ESG performance of enterprises.

This leads to the hypothesis H2 of this paper:

H2 : Green innovation mediates the “inverted U-shaped” relationship between the rate of digital transformation and firms' ESG performance

3. Research Design

3.1. Sample Selection and Data Sources

Referring to the studies of (WANG Yinghuan et al., 2023 ; GUO Huiting et al., 2024) [9][10] and considering that China has entered the digital era since 2010, this paper takes Shanghai and Shenzhen A-share listed companies as the initial research samples, selects the data from 2011-2023, and excludes the samples of companies with serious missing data, listed companies of finance and insurance as well as ST and *ST samples, and finally obtains 24869 valid samples.

In terms of data sources, the green patent data comes from the China Research Data Service Platform (CNRDS), the digital transformation data is a reference to the study of (WU Fei et al., 2021) [11] , which is obtained by textual analysis of keywords in the annual reports of listed companies, the CSI ESG data comes from the Wind database, and the other data comes from the

database of Cathay Pacific (CSMAR). In addition, in order to eliminate the effect of extreme values, this paper shrinks the main continuous variables by 1% and 99%.

3.2. Variable Definition

3.2.1. Explained Variable: ESG

Given that the CSI ESG ratings are now widely recognized by scholars, this paper assigns the 9 levels of the CSI ESG ratings 9-1 in order from high to low, and based on this, the annual average of the comprehensive ESG performance is used as the ESG score of company *i* in year *t*. The larger the value is, the better the ESG performance of the company.

3.2.2. Explanatory Variables: Rate of Digital Transformation(DigRate)

In this paper, we refer to the study of (Wu Fei et al., 2021) [11], which measures the degree of digital transformation (Dig) by adding the logarithm of the digital transformation word frequency statistics of the annual reports of listed companies, and draws on the study of (Guo Huiting et al., 2024) [10], which measures the degree of digital transformation based on the growth rate of the degree of digital transformation in the current year compared with the degree of digital transformation in the previous year. Rate (DigRate), the calculation formula is as follows:

$$DigRate_{i,t} = \frac{Dig_{i,t} - Dig_{i,t-1}}{Dig_{i,t-1}}$$

3.2.3. Control Variable

Drawing on the study of (Guo Huiting et al.,2024) [10], this paper selects firm size (Size), board size (Board), gearing ratio (Lev), nature of property rights (Soe), two positions (Daul), equity concentration (Top1), percentage of independent directors (Indep), and management shareholding ratio (Mshare) as control variables. Dummy variables for year and industry are also added.

3.3. Model Construction

3.3.1. Benchmark Regression Model

In order to test hypothesis H1, referring to the research of (Guo Huiting et al., 2024) [10], the benchmark regression model (1) is constructed as follows:

$$ESG_{i,t} = \alpha_0 + \alpha_1 DigRate_{i,t} + \alpha_2 DigRate_{i,t}^2 + \alpha_3 Controls_{i,t} + \sum year + \sum Ind + \varepsilon_{i,t} \quad (1)$$

Among them, *i* represents the enterprise, *t* represents the time, Controls is the relevant control variable, $\sum year$ represents the time fixed effect, $\sum Ind$ represents the industry fixed effect, which $\varepsilon_{i,t}$ is a random disturbance term. If the coefficient of α_1 is significantly positive and the coefficient of α_2 is significantly negative, Indicates the existence of an inverted U-shaped relationship between a firm's rate of digital transformation and its ESG performance, supporting the research hypothesis of this paper.

3.3.2. Mediation Effect Regression Model

Referring to the mediation test method (Lin Weipeng et al., 2022) [12], This paper sets up the following model to test the mediating role of green innovation in the inverted U-shaped relationship between firms' digital transformation rate and ESG performance

$$AGreen_{i,t} = \alpha_0 + \alpha_1 DigRate_{i,t} + \alpha_2 DigRate_{i,t}^2 + \alpha_3 Controls + \sum year + \sum Ind + \varepsilon_{i,t} \quad (2)$$

$$ESG_{i,t} = \alpha_0 + \alpha_1 DigRate_{i,t} + \alpha_2 DigRate_{i,t}^2 + \alpha_3 AGreen_{i,t} + \alpha_4 Controls + \sum year + \sum Ind + \varepsilon_{i,t} \quad (3)$$

In this case, green innovation (AGreen) is the explanatory variable in model (2), and digital transformation rate (DigRate) and the square of digital transformation rate (DigRate2) are the explanatory variables. ESG is the explanatory variable in model (3), and digital transformation rate (DigRate), square of digital transformation rate (DigRate2), and green innovation (AGreen) are the explanatory variables, if α_1 is significantly positive and α_2 is significantly negative in model (2), and if α_1 and α_3 are significantly positive and α_2 is significantly negative in model (3), then it indicates that the green innovation of the enterprise (AGreen) in digitalization transformation rate (DigRate) has a mediating role in the inverted U-shaped relationship with its ESG performance.

4. Empirical Analysis

4.1. Descriptive Statistics and Analysis

The results in Table 1 show that the maximum value of ESG performance score is 6.25, and the minimum value is 1.5, Indicates large differences in corporate ESG scores, and the median 4 is smaller than the mean 4.197, indicating that the overall ESG performance of the enterprise needs to be improved. The median rate of digital transformation is 0 and the mean is 0.018, which is smaller than the mean, indicating that there is an overall low rate of digital transformation.

Table 1. Descriptive Statistics

Variable	N	Mean	p50	SD	Min	Max
ESG	24869	4.197	4	0.913	1.500	6.250
DigRate	24869	0.0180	0	0.511	-1	2
Size	24869	22.32	22.13	1.311	20.00	26.41
SOE	24869	0.315	0	0.464	0	1
Board	24869	2.103	2.197	0.199	1.609	2.639
Top1	24869	0.326	0.302	0.146	0.0800	0.740
Indep	24869	37.96	36.36	5.445	33.33	57.14
Dual	24869	0.319	0	0.466	0	1
Mshare	24869	14.69	2.582	19.48	0	67.79
Lev	24869	0.418	0.409	0.201	0.0590	0.900

4.2. Benchmark Regression Results and Analysis

To explore the relationship between transition rate and firms' ESG performance, this paper empirically analyzes Model 1. Column (1) in Table 2 only considers year and industry fixed effects, while column (2) further adds other control variables on this basis. It can be seen that, regardless of whether the control variables are added, the coefficient of the primary term of the digitization transition rate is significantly positive at the 1% level, the coefficient of the secondary term of the transition rate is significantly negative at the 1% level, and the transition rate at the inflection point of the curve is $0.468 = [-0.029 / (2 \times 0.031)]$, which is located in the range of the independent variable from the minimum to the maximum value $[-1, 2]$. It shows that there is an "inverted U-shaped" relationship between the two, which indicates that the ESG performance of enterprises rises and then falls with the increase of transformation rate, which is consistent with hypothesis H1.

Table 2. Return To Baseline

Variable	(1)	(2)
	ESG	ESG
DigRate	0.063***	0.029***
	(5.19)	(2.58)
DigRate ²	-0.058***	-0.031***
	(-5.47)	(-3.15)
Size		0.291***
		(53.14)
SOE		0.069***
		(4.89)
Board		0.170***
		(4.77)
Top1		0.416***
		(10.65)
Indep		0.013***
		(11.06)
Dual		-0.003
		(-0.24)
Mshare		0.006***
		(18.32)
Lev		-1.250***
		(-37.69)
Constant	4.214***	-2.891***
	(672.49)	(-20.49)
Year	Yes	Yes
Ind	Yes	Yes
R ²	0.0699	0.206
F	20.49	418.5
Observations	24,645	24,025

4.3. Robustness Check

4.3.1. Utest Test

In this paper, we incorporate the Utest test with reference to (Guo Huiting et al., 2024) [10]. The result of the test shows that the value of transition rate is between [-1,2]. This results in the extreme point of 0.468 falling within the range of the data and the result is able to reject the original hypothesis at 1% level of significance. In addition, the interval of the slope is [-0.267, 0.251], which contains negative values, indicating that the effect of transition rate on the ESG performance of enterprises shows an “inverted U-shaped” relationship, which is consistent with the previous results.

4.3.2. Adding High Order Terms

In this paper, we refer to the practice of (Wang Yu et al., 2025) [13], adding the cubic term in the model for regression, and column (1) of Table 3 shows that the coefficient of the cubic term is not significant, proving that the “inverted U-shaped” relationship is robust.

4.3.3. Replacement of Explanatory Variable Measures

Drawing on the practice of (Zhang Yongkun et al., 2021)[14], the year-end intangible asset breakdown items disclosed in the notes of listed companies' financial reports are used to find the part related to digital transformation, and its proportion of total intangible assets is

calculated to portray the degree of digital transformation of enterprises, and the digital transformation rate of enterprises in the current year is further calculated to test whether the conclusions of this paper are robust or not. The results in column (2) of the results in Table 3 show that they are consistent with the previous hypotheses, proving that the conclusions of this paper are robust.

4.3.4. Lagged Core Explanatory Variables

Considering the two-way causality issue, the core explanatory variables are lagged by one period and re-regressed against firms' ESG performance. The results in column (3) of Table 3 show that the regression coefficients of the lagged one-period explanatory variables, L.DigRate, are 0.092 and L.DigRate2 is -0.054, and both are significant at the 1% statistical level, which is in line with the initial results, and proves that the conclusions of this paper are robust.

Table 3. Robustness Check

	(1)	(2)	(3)
Variable	ESG	ESG	ESG
DigRate	0.030	0.016**	
	(1.60)	(2.24)	
DigRate ²	-0.030**	-0.001***	
	(-1.98)	(-2.59)	
DigRate ³	-0.001		
	(-0.06)		
L.DigRate			0.092***
			(3.78)
L.DigRate ²			-0.054***
			(-3.07)
Controls	Yes	Yes	Yes
Constant	-2.891***	-2.770***	-3.093***
	(-20.48)	(-16.96)	(-18.85)
Year	Yes	Yes	Yes
Ind	Yes	Yes	Yes
Observations	24,025	18,594	17,909
R ²	0.206	0.199	0.212
F	380.4	311.3	322.1

4.4. Mechanism Testing

In order to test the hypothesis H2, this paper refers to the study of (Li Chunxia et al., 2024) [15], and adopts the number of green patent applications (AGreen) of enterprises in the current year to measure the green innovation level of enterprises. The results in column (1) of Table 4 show an “inverted U-shape” relationship between the digital transformation rate and the green innovation capability of enterprises, which, combined with the regression results in column (2) of Table 4, proves that green innovation plays a mediating role in the “inverted U-shape” relationship between the transformation rate and the ESG performance of enterprises, and the hypothesis H2 is validated. The hypothesis H2 is verified.

Table 4. Mechanism Test

	(1)	(2)
Variable	ESG	ESG
AGreen		0.118***
		(17.38)
DigRate	0.020*	0.027**
	(1.89)	(2.38)
DigRate ²	-0.039***	-0.026***
	(-4.17)	(-2.70)
Controls	Yes	Yes
Constant	-3.901***	-2.433***
	(-29.25)	(-17.05)
Year	Yes	Yes
Ind	Yes	Yes
Observations	24,022	24,022
R ²	0.190	0.216
F	179.9	412.8

4.5. Heterogeneity Analysis

4.5.1. A Heterogeneous Group Test for the Nature of Business Ownership

Unlike non-SOEs, SOEs are usually influenced by the government's policy orientation and take on more social responsibility, so their ESG performance tends to be more stable and less prone to large fluctuations due to changes in external or own factors. Non-state-owned enterprises, on the other hand, focus more on market competition and prioritize efficiency, and tend to improve productivity through digital transformation to achieve cost savings and efficiency growth. The results of columns (1) and (2) of Table 6, which were tested by grouping the samples with different nature of firms' ownership, show that there is a significant inverted U-shaped relationship between the rate of digital transformation and its ESG performance among non-state-owned firms, while no significant correlation was found among state-owned firms, which suggests that non-state enterprises usually have more flexible decision-making mechanism and management structure in the wave of digital transformation, and they can quickly respond to market changes and technological innovation, and can achieve better ESG performance by relying on the support of external technology and resources during the transformation process, but if NSOEs over-pursuing the increase in the rate of digital transformation, they may neglect environmental and social responsibility, which will lead to the reduction of their ESG performance.

4.5.2. Heterogeneity Analysis Test for Industry Traits

In recent years, high-tech enterprises have been supported by the state focusing on the wave of digital transformation, and tend to focus on their ESG performance in order to obtain more support. In this paper, we refer to the study of (Jun Hu et al., 2024) [16] and divide the sample into high-tech enterprises and non-high-tech enterprises. The results in columns (3) and (4) of Table 6 show that in high-tech enterprises, the coefficient of the primary term of the transformation rate is 0.069 and the coefficient of the secondary term is -0.065, and both are significant at the 1% level, and an inverted U-shaped relationship exists. This suggests that high-tech firms receive greater benefits in terms of social, environmental, and corporate governance through digital transformation.

4.5.3. Heterogeneous Grouping Tests for Enterprise Regions

Considering that the development of the digital economy in different regions of China is not evenly distributed spatially, the pace of the digital transformation process is not consistent,

which may result in uneven ESG performance between regions. In this paper, the provinces where the sample enterprises are located are divided into three groups by geographic location into East, Central and West for group regression, and the results of columns (5) to (7) in Table 5 show that in the East, the coefficient of the primary term of the transformation rate is significantly positive at the 1% level, and the coefficient of the quadratic term is -0.034, and it is significant at the 1% level. This indicates that in the eastern region, because of its high digital economic environment, enterprises can effectively use external resources to improve the degree of digital transformation, so that enterprises can better optimize the efficiency of their resource allocation, faster to achieve cost reduction and efficiency gains, so that enterprises can achieve sustainable development.

Table 5. Heterogeneity Test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Non-municipal	Nationalized	High tech	Non-high-tech	East	Central	West
Variable	ESG	ESG	ESG	ESG	ESG	ESG	ESG
DigRate	0.051***	-0.002	0.069***	-0.021	0.033**	0.008	0.051
	(3.62)	(-0.10)	(4.63)	(-1.21)	(2.50)	(0.29)	(1.56)
DigRate ²	-0.049***	0.002	-0.065***	0.011	-0.034***	-0.015	-0.034
	(-4.05)	(0.10)	(-4.98)	(0.75)	(-2.94)	(-0.61)	(-1.13)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-2.548***	-3.450***	-3.094***	-2.764***	-2.910***	-2.378***	-3.012***
	(-13.64)	(-15.14)	(-15.88)	(-13.55)	(-17.68)	(-6.21)	(-6.77)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16,363	7,659	12,798	11,227	18,038	3,594	2,372
R ²	0.182	0.290	0.178	0.244	0.211	0.212	0.251
F	258.0	195.4	226.9	207.7	316.5	47.72	42.33

5. Conclusion and Implications of the Study

5.1. Findings

ESG performance, as an important embodiment of the concept of sustainable development of enterprises, plays a key role in promoting the high-quality development of China's economy and society. This paper empirically examines the relationship between digital transformation rate and corporate ESG performance using digital transformation rate as an entry point. The research conclusions show that:

There is an “inverted U-shaped” relationship between the rate of digital transformation and the ESG performance of enterprises. At the initial stage of transformation, the transformation rate improves the ability of enterprises to obtain external resources, reduces inefficient investment, and improves the ESG performance of enterprises; however, when the transformation rate is too fast, enterprises tend to obtain economic gains in the short term, which gradually crowds out the investment in ESG performance, and reduces the ESG performance.

Green innovation partially mediates the inverted U-shaped relationship between the rate of digital transformation and ESG scores. The “inverted U-shaped” relationship between the rate of transformation and firms' ESG performance is particularly pronounced for non-state-owned firms, high-tech firms, and firms in the eastern region, which may be closely related to the different characteristics of these firms in terms of competition in the market, technological innovation, and regional policy support.

5.2. Apocalypse

The following management insights were gained from the above study:

Enterprises should control the rate of transformation in the digital transformation process within a reasonable interval and gradually promote digital transformation. For enterprises, an increase in the rate of digital transformation can certainly reflect the degree of digital-real integration, thus promoting the level of green innovation and ESG performance of enterprises. However, the increasing rate of transformation will make the enterprise unable to coordinate the combination of digital technology resources and existing resources, resulting in the reduction of green innovation ability and the reduction of enterprise ESG performance.

In the wave of digital transformation, the government should join hands with enterprises to promote it. Enterprises should pay attention to social, environmental and corporate governance, actively carry out digital transformation, and at the same time actively learn from high-tech enterprises and enterprises in the eastern region, take the best and remove the dross, and actively promote the digital transformation; the government should accurately implement measures to increase the policy orientation of state-owned enterprises, non-high-tech enterprises, and the central and western regions, and help enterprises to The government should implement precise measures and increase policy guidance for state-owned enterprises, non-high-tech enterprises and enterprises in central and western regions, so as to help enterprises enhance their ability to obtain external resources and promote all kinds of enterprises to focus on the improvement of ESG performance.

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