Research on the Impact of Digital Transformation in Manufacturing Enterprises on Environmental Performance

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Abstract. With the rapid advancement of information technology, digital transformation has become an essential development direction for the vast majority of enterprises. This study aims to thoroughly analyze the impact of digital transformation on the environmental performance of manufacturing companies. Using data from A-share listed manufacturing companies in China from 2011 to 2022 as the research sample, an empirical study is conducted on the relationship between digital transformation and environmental performance, further discussing the moderating effects of property rights and internal control.

Keywords: Digital Economy; Digital Transformation; Environmental Performance; Internal Control

1 Introduction

The report of the 20th National Congress of the Communist Party emphasizes the importance of leveraging massive data and diverse application scenarios to promote the deep integration of digital technology and the real economy. This integration aims to empower the transformation and upgrading of traditional industries, foster the emergence of new industries, business formats, and models, and accelerate the development of China's digital economy. Digital enterprises are a vital component of the digital economy's development; robustly fostering and supporting their digital transformation is essential for the healthy and rapid advancement of the digital economy. Furthermore, enterprises seeking long-term growth must prioritize digital transformation in response to national calls, especially within the manufacturing sector. This transformation incorporates emerging technologies such as blockchain, revitalizing and upgrading traditional business models—representing a high-level transformation.[1] The application of digital technologies can assist enterprises in reducing costs and increasing efficiency, thereby enhancing their production and operational activities. Additionally, green development is a critical national strategy; digital transformation introduces digital technologies and optimizes operational processes to provide new pathways for enterprises' green development. Existing research shows that digital transformation can enhance not only economic performance but also play a crucial role in environmental protection.

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Therefore, studying the impact of digital transformation in manufacturing on corporate environmental performance offers insights into the development of China's digital economy. This paper intends to employ empirical analysis to explore the impact of digital transformation on environmental performance among listed manufacturing companies from 2011 to 2022, while also verifying the moderating effects of property rights and internal control.

2 Theoretical Analysis and Research Hypotheses

2.1 Digital Transformation and Environmental Performance

Firstly, Pang R Z et al. (2021) demonstrated that digitization has an "amplification" effect. This effect indicates that digital transformation can significantly enhance corporate environmental governance performance, particularly in regions with low environmental governance standards. Digitization facilitates cooperation between governments, businesses, and the public. It does this by strengthening the enforcement of environmental regulations, increasing public participation, and promoting innovation in green technologies, thereby improving corporate environmental governance performance[2]. Secondly, research indicates that the environmental performance of manufacturing enterprises has notably improved during the digital transformation process. Traditional industrial production methods rely heavily on natural resources, leading to significant resource consumption. In contrast, digital technologies can utilize shared data as a key production factor, reducing waste and enhancing environmental performance[3]. Additionally, digital transformation encourages companies to innovate in green technologies. By employing advanced clean production techniques, firms can improve their product innovation capabilities, ultimately enhancing their environmental performance[4-5]. Finally, within the prevailing context of digital technologies, companies not only create commercial value but also showcase their commitment to social responsibility[6]. At the same time, Zhao C Y (2022) indicated that digital transformation can drive firms to fulfill greater social responsibilities through improved overall innovation capability and green innovation capability[7].

Based on this analysis, the following hypothesis is proposed:

H1: Digital transformation can promote corporate environmental performance.

2.2 The Regulatory Role of Property Rights Characteristics

Gao et al. (2024) conducted a study on the impact of digital transformation on the environmental and social performance of enterprises. They found that the digital transformation of state-owned enterprises significantly influences both environmental and social performance. State-owned enterprises benefit from government support, making resource acquisition easier and enabling a more proactive approach to digital transformation. Consequently, these enterprises take on more social responsibilities and are subject to stricter oversight, such as environmental protection. In contrast, private enterprises face more challenges in achieving digital transformation, including funding

shortages and difficulties in innovative technologies. This, to some extent, limits their investments in environmental protection and social responsibility[8].

Based on this analysis, the following hypothesis is proposed:

H2: Digital transformation promotes environmental performance more effectively in state-owned enterprises.

2.3 The Regulatory Role of Internal Controls

When examining the impact of internal control on environmental performance in the context of digital transformation, Zhang Q C, Yang M Z (2022) [9], Wang C et al. (2023) [10], and Xu Kai et al. (2014) [11] found that an internal control system can assess the risks related to an enterprise's environmental performance and implement effective control measures to mitigate environmental liability risks. Furthermore, digital transformation enhances the efficiency and effectiveness of risk assessments. Digital technologies, with their robust data collection and processing capabilities, enable enterprises to perceive changes in risk assessment information in real time, improving both risk assessment efficiency and internal control quality. This allows for a more effective evaluation of environmental performance while reducing environmental liability risks. In addition to this, an internal control system can effectively safeguard organizational resources and minimize the wastage of natural resources. By undergoing digital transformation, enterprises can harness technologies to process complex and chaotic data, obtain timely information, enhance internal communication efficiency, and effectively reduce information asymmetry. This subsequently protects investor interests and boosts external investors' confidence in the company's operational status. Consequently, enterprises are likely to attract increased funding, which can, in turn, support improvements in environmental performance.

Based on this analysis, the following hypothesis is proposed:

H3: Digital transformation is more effective in promoting environmental performance in companies with high levels of internal control.

3 Research Design

3.1 Sources of Data and Sample Selection

This study focuses on A-share manufacturing listed companies in China from 2011 to 2022. The research sample underwent several treatments: exclusion of samples from financial sectors; removal of ST, *ST, and PT samples; elimination of samples with partial data loss; and winsorization of continuous variables at the 1% level. Relevant variables and financial data were sourced from the CSMAR database and the Wind database.

3.2 Model Design

This paper primarily examines the impact of digital transformation on the environmental performance of manufacturing enterprises. To validate the hypothesis, we reference existing literature[12-13] and construct the following model:

$$CSR_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 SOE_{i,t} + \alpha_3 Digital_{i,t} * SOE_{i,t} + \alpha_4 Control_{i,t} + \delta_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

$$CSR_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 SOE_{i,t} + \alpha_3 Digital_{i,t} * SOE_{i,t} + \alpha_4 Control_{i,t} + \delta_i + \delta_t + \varepsilon_{i,t} \quad (2)$$

$$CSR_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 IC_{\hat{i},t} + \alpha_3 Digital_{i,t} * IC_{\hat{i},t} + \alpha_4 Control_{i,t} + \delta_i + \delta_t + \varepsilon_{i,t} \quad (3)$$

In model (1), CSR represents corporate economic performance, Digital indicates the level of corporate digitalization, and Control refers to control variables. δi and δt denote fixed effects for firms and years, respectively, while ε represents the random error term. Coefficient α1 reflects the impact of corporate digital transformation on environmental performance. If coefficient α1 is significantly positive, it indicates that digital transformation enhances corporate environmental performance. In models (2) and (3), based on the research method of Wen Z L (2005)[14], interaction terms X*Z are constructed, where X represents digital transformation, Z1 signifies ownership structure, and Z2 refers to internal control quality. If a significant relationship exists between the explanatory variable X and the explained variable Y, and if the interaction term X*Z is significant, it demonstrates the presence of a moderating effect.

3.3 Variable Definition

Dependent Variable.

Corporate environmental performance, referencing the research of Jia X P (2017)[15], employs the total score of corporate social responsibility ratings published by third-party organizations to measure environmental performance, denoted as CSR.

Explanatory Variable.

Digital transformation involves acquiring textual word frequency data related to enterprise digitalization from the CSMAR database. Following the research by Wu F et al. (2021) [16], keywords for digital transformation are categorized. The first level divides into two aspects: "fundamental technology applications" and "technological practice applications." Building on this, "fundamental technology applications" is further subdivided into four directions: artificial intelligence, big data, cloud computing, and blockchain technology. Meanwhile, "technological practice applications" focus on specific digital application scenarios. After classification, the related keywords' frequency is organized to evaluate enterprises' digital transformation. Given that word frequency data exhibit "right skewness," this paper adds one to the total word frequency data and then takes the natural logarithm.

Adjusting Variables.

Property rights classification refers to the existing literature that categorizes firms as state-owned or non-state-owned. Using 0 and 1 to represent values, state ownership is assigned a value of 1. The quality of internal control relies on the study by Cao Y et al. (2020) [17] and measures the level of corporate internal control using the "Internal Control Index" disclosed in the DIB database. Here, IC equals the Internal Control Index divided by 100; a higher index value indicates superior internal control quality within the enterprise.

Control Variables.

To enhance the accuracy of the research, this paper includes a range of factors that may influence environmental performance as control variables.

4 Empirical Analysis

4.1 Benchmark Regression

In Table 1, columns (1) and (2) only consider digital transformation (Digital) as the core explanatory variable for baseline regression analysis. The results indicate that digital transformation in enterprises passes the significance test at the 1% level, with coefficients of 0.413 and 0.129. This finding suggests that digital transformation positively influences the environmental performance of manufacturing industries. After incorporating control variables, columns (3) and (4) show that the regression coefficient for digital transformation remains significantly positive at the 1% level. Thus, it is evident that after adding the aforementioned variables, the relationship between digital transformation and environmental performance in manufacturing enterprises consistently remains significantly positive. Therefore, digital transformation enhances corporate environmental performance, validating hypothesis H1.

Table 1. Results of the Direct Effect of Digital Transformation on Corporate Environmental Performance.

Variable	(1) CSR	(2) CSR	(3) CSR	(4) CSR
Didital	0.413***	0.129***	0.323***	0.086***
	(41.89)	(9.14)	(31.79)	(6.00)
Size			0.817***	0.455***
			(68.11)	(18.48)
Lev			-1.813***	0.342***
			(-23.34)	(3.44)
ATO			-0.033	0.127***
			(-1.11)	(2.62)
Cashflow			1.351***	0.398**
			(6.92)	(2.40)
INV			0.157	0.307*

			(1.42)	(1.87)
Fixed			0.360***	0.400***
			(3.86)	(3.04)
Growth			-0.375***	-0.160***
			(-11.28)	(-5.83)
Board			-1.080***	-0.146
			(-13.58)	(-1.37)
Indep			-0.012***	-0.001
			(-4.32)	(-0.41)
Dual			0.317***	-0.067**
			(10.73)	(-2.00)
_cons	3.810***	4.155***	-10.778***	-5.830***
	(207.22)	(210.16)	(-35.31)	(-9.69)
N	42073	41635	42073	41635
r2_a	0.040	0.610	0.146	0.615

Note: *Significant at levels of 10%, 5%, and 1% are denoted by *, **, and *** respectively; the values in parentheses indicate the t-values, and the same applies throughout.

Testing the Moderating Effect of Property Rights Nature.

Table 2 results show that the interaction term between property rights and enterprise digital transformation (Digital*SOE) has a coefficient of 0.0558, which is significantly positive at the 5% level. This indicates that the digital transformation in manufacturing firms within state-owned enterprises more clearly improves environmental performance, thereby validating hypothesis H2.

Table 2. Results of the Adjustment Effect Test on Property Rights Nature.

Variable	(1) CSR	(2) CSR	(3) CSR
Digital	0.4007***	0.3692***	0.3890***
	(0.0138)	(0.0166)	(0.0143)
Size	1.4618***	1.4975***	1.4975***
	(0.0196)	(0.0207)	(0.0207)
Lev	-0.2207**	-0.2822***	-0.2822***
	(0.0990)	(0.1063)	(0.1063)
ATO	-0.0928*	-0.0727	-0.0727
	(0.0481)	(0.0510)	(0.0510)
Cashflow	0.8770***	0.9311***	0.9311***
	(0.1735)	(0.1809)	(0.1809)
INV	-0.3288**	-0.3099*	-0.3099*
	(0.1617)	(0.1717)	(0.1717)
Fixed	0.1018	0.1982	0.1982
	(0.1334)	(0.1401)	(0.1410)
Growth	-0.4299***	-0.4255***	-0.4255***

	(0.0271)	(0.0284)	(0.0284)
Board	-1.2655***	-1.2895***	-1.2895***
	(0.1059)	(0.1124)	(0.1124)
Indep	0.0019	-0.0003	-0.0003
	(0.0033)	(0.0035)	(0.0035)
Dual	-0.0851**	-0.0755**	-0.0755**
	(0.0347)	(0.0363)	(0.0363)
SOE		-0.2209***	-0.1506**
		(0.0784)	(0.0728)
Digital*SOE		0.0558**	
		(0.0247)	
Digital*SOE_c			0.0558**
			(0.0247)
_cons	-25.6508***	-26.1855***	-26.2105***
	(0.5215)	(0.5514)	(0.5512)
N	42073	38795	38795
R^2	0.1787	0.1781	0.1781

Examination of the Moderating Effects of Internal Controls.

Table 3 shows that the interaction term for internal control and digital transformation of enterprises (Digital*IC) has a coefficient of 0.0002, which is significantly positive at the 1% level. This indicates that when the quality level of internal control is high, the impact of digital transformation on the environmental performance of manufacturing enterprises is more pronounced, thus validating hypothesis H3.

Table 3. Results of the examination of the moderating effects of internal control

Variable	(1) CSR	(2) CSR	(3) CSR
Digital	0.4007***	0.2287***	0.3587***
	(0.0138)	(0.0433)	(0.0145)
Size	1.4618***	1.4020***	1.4020***
	(0.0196)	(0.0202)	(0.0202)
Lev	-0.2207**	-0.5945***	-0.5945***
	(0.0990)	(0.1031)	(0.1031)
ATO	-0.0928*	0.0629	0.0629
	(0.0481)	(0.0500)	(0.0500)
Cashflow	0.8770***	0.6719***	0.6719***
	(0.1735)	(0.1800)	(0.1800)
INV	-0.3288**	-0.5804***	-0.5804***
	(0.1617)	(0.1646)	(0.1646)
Fixed	0.1018	-0.5757***	-0.5757***
	(0.1334)	(0.1386)	(0.1386)
Growth	-0.4299***	-0.4093***	-0.4093***
	(0.0271)	(0.0278)	(0.0278)

Board	-1.2655***	-1.1284***	-1.1284***
	(0.1059)	(0.1091)	(0.1091)
Indep	0.0019	0.0036	0.0036
	(0.0033)	(0.0034)	(0.0034)
Dual	-0.0851**	-0.0621*	-0.0621*
	(0.0347)	(0.0362)	(0.0362)
IC		-0.0011***	-0.0008***
		(0.0001)	(0.0001)
Digital*IC		0.0002***	
		(0.0001)	
Digital*IC_c			0.0002***
			(0.0001)
_cons	-25.6508***	-23.7706***	-23.9343***
	(0.5215)	(0.5444)	(0.5398)
N	42073	38405	38405
R^2	0.1787	0.1607	0.1607

5 Conclusion and Implications

5.1 Research Conclusions

This study explores the impact of digital transformation on environmental performance. Additionally, it examines how property rights and internal control moderate this relationship. The findings reveal that: (1) Digital transformation significantly enhances environmental performance. The higher the level of digital transformation in a manufacturing enterprise, the better its environmental performance. (2) Compared to non-state-owned enterprises, state-owned enterprises show a more pronounced effect of digital transformation on environmental performance. (3) In enterprises with high-quality internal control, digital transformation more effectively promotes environmental performance compared to those with lower internal control quality.

5.2 The Significance of Revelation

Researching the impact of digital transformation in manufacturing enterprises on environmental performance holds significant implications for future studies and practices. First, empirical studies investigating this relationship can provide strong empirical support to the academic community, validating the reasonableness and effectiveness of relevant theoretical hypotheses. Moreover, these empirical findings can serve as a data foundation and reference for subsequent research, promoting deeper developments in related studies. Second, the results can offer scientific evidence and references for enterprises in formulating green transformation strategies. Companies can plan and advance their digital transformation process according to their unique circumstances to enhance environmental performance.

In summary, digital transformation in enterprises, by incorporating modern information technology, not only boosts production efficiency but also facilitates more efficient environmental management, while combining green processes to minimize negative environmental impacts. Therefore, manufacturing enterprises should fully recognize the crucial role of digital transformation in enhancing environmental performance and increase their investment in this area. Furthermore, digital transformation requires specialized talent for implementation and promotion; thus, enterprises should focus on nurturing professionals who possess both technical and business acumen. Additionally, companies ought to strengthen collaboration and communication with research institutions and universities to jointly drive innovation and application of green technologies.

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