The Impact of Digital Transformation on Total Factor Productivity: the Mediating Role of ESG Performance

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Abstract. This study was based on data from A-share listed companies in Shanghai and Shenzhen from 2009 to 2022. It aimed to investigate the impact of digital transformation on total factor productivity and its underlying mechanisms. The findings indicated a significant enhancement in corporate total factor productivity due to digital transformation, with effects varying based on company size and ownership structure. Through an analysis of the operational mechanisms, it was revealed that digital transformation enabled companies to have more financial resources by easing financial constraints and lowering financing expenses. Consequently, this facilitates increased investment in research and development and innovation activities, establishing a positive cycle of "digital transformation-resource mobilization-innovation reinforcement-productivity enhancement." This study offered empirical evidence supporting the economic advantages of digital transformation, elucidated its diverse impact pathways, and provided valuable insights for the development of tailored digital transformation policies.

Keywords: digital transformation; total factor productivity; ESG; empirical analysis.

1 Introduction

The 20th National Congress of the Communist Party of China underscores that achieving high-quality development is paramount in the comprehensive construction of a modern socialist nation, with an emphasis on enhancing total factor productivity (TFP) as the principal approach. Against the backdrop of the rapid advancement of the digital economy, technologies such as big data, cloud computing, and artificial intelligence are profoundly facilitating business operations and driving digital transformation as a central strategy for enterprises to bolster their competitiveness[1,2]. Digital transformation plays a vital role in enhancing enterprise TFP through the optimization of resource allocation, reduction of transaction costs, and augmentation of innovation capabilities[3,4]. However, the specific mechanisms and diverse impacts of digital transformation necessitate further exploration and analysis.

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Simultaneously, the significance of environmental, social, and governance (ESG) performance as a key metric of corporate sustainability is growing[5]. Prior studies indicate that digital transformation can influence ESG performance by enhancing governance frameworks and increasing transparency in information disclosure, subsequently impacting firm productivity indirectly[6-8]. Nevertheless, comprehensive research on the interplay among digital transformation, ESG performance, and TFP remains limited, particularly in terms of empirical analysis utilizing enterprise-level data[9,10].

This study examined A-share listed companies in Shanghai and Shenzhen from 2009 to 2022 to quantitatively assess the level of digital transformation and TFP. It introduced ESG performance as a mediating variable to investigate how digital transformation impacted TFP through mechanisms and heterogeneous characteristics. The research contributes to enhancing the theoretical framework of the economic effects of digital transformation and offers practical insights for firms to optimize digital technology utilization and improve their capacity for sustainable development.

2 Theoretical Analysis and Research Assumptions

2.1 Impact of Digital Transformation on TFP

Digital transformation optimizes business operations through three key phases: management digitization, value chain digitization, and data digitization. Management digitization enhances internal process efficiency, value chain digitization improves external resource integration, and data digitization enables intelligent decision-making. These digitalization efforts collectively reduce transaction costs, enhance the utilization of production factors, and ultimately boost TFP.

H1: Digital transformation has a significant positive impact on TFP.

2.2 The Mediating Role of ESG Performance

Digital transformation helps companies improve ESG performance through technology openness and data sharing:

Digital technologies optimize resource scheduling, reduce pollution, and enhance green innovation (E). Digitalization facilitates stakeholder communication, improves product quality, and enhances service experience (S). By digitally breaking information silos, governance transparency and decision-making efficiency can be improved (G). Optimizing ESG performance further promotes TFP growth.

H2: Digital transformation indirectly boosts TFP by improving ESG performance.

2.3 Heterogeneous Effects

Enterprise size: Small and medium-sized enterprises rely more on digital transformation to ease financing constraints, while large enterprises focus on collaborative optimization of supply chain.

Nature of Ownership: State-owned enterprises benefit from a stable management structure, while non-state-owned enterprises use digitalization to reduce financing costs.SMEs rely more on digital transformation to ease financing constraints, while large enterprises focus on supply chain collaboration and optimization. Consequently, the following proposition is suggested:

H3: The contribution of digital transformation to TFP is heterogeneous depending on firm size and ownership nature.

3 Study Design

3.1 Data Sources

This study analyzed data from Shanghai and Shenzhen A-share listed companies between 2009 and 2022, excluding the financial industry, ST/PT enterprises, and samples with significant data gaps. The study applied 1% and 99% tail trimming to continuous variables, resulting in unbalanced panel data.

3.2 Variable Definitions

Explained variable: TFP, measured by Levinsohn-Petrin (LP) semiparametric method, and tested by Olley-Pakes (OP) method.

Explanatory variable: Digital transformation, based on the annual report text of listed companies crawled by Python, constructs word frequency indicators containing keywords such as big data and cloud computing.

Mediating variable: ESG performance, measured by ESG rating percentile data.

Control variables: Size, Age, state-owned business, CASH, ROA, LEV, TOP1, INDBR, firm, and year fixed effects.

3.3 Model Setting

In order to investigate the impact of enterprise digital transformation on TFP, this study constructed the reference regression model. To test the mediating effect of ESG between enterprise digital transformation and TFP, the mediating effect test model was constructed by referring to the previous mediating effect test procedure:

$$\mathrm{TFP}_{i,t} = \beta_0 + \beta_1 \,\mathrm{Digital}_{i,t} + \beta_2 \,\mathrm{Controls}_{i,t} + \mathrm{Year} + \mathrm{Industry} + \varepsilon_{i,t} \quad (1)$$

$$\mathrm{ESG}_{i,t} = \beta_0 + \beta_1 \,\mathrm{Digita}_{i,t} + \beta_2 \,\mathrm{Controls}_{i,t} + \mathrm{Year} + \mathrm{Industry} + \varepsilon_{i,t} \quad (2)$$

$$\mathrm{TFP}_{i,t} = \beta_0 + \beta_1 \,\mathrm{Digital}_{i,t} + \beta_2 \,\mathrm{ESG}_{i,t} + \beta_3 \,\mathrm{Controls}_{i,t} + \mathrm{Year} + \mathrm{Industry} + \varepsilon_{i,t} \quad (3)$$

Where $\mathrm{TFP}_{i,t}$ is the explanatory variable, indicating the total factor productivity level of enterprise i calculated by LP method in t years; $\mathrm{Digita}_{i,t}$ is the core explanatory variable, indicating the digital transformation level of enterprise i in t years; is a series

of control variables, and represent fixed effects of enterprise and year respectively, and C is a random disturbance term.

4 Empirical Analysis

4.1 Analysis of Results of Benchmark Regression

The result of the baseline regression showed that digital transformation had a significant positive impact on TFP (Table 1). Upon systematic inclusion of firm fixed effects, year fixed effects, and other control variables, the coefficient for "Digital" consistently demonstrated a statistically significant positive association at the 1% level. It confirmed hypothesis H1. These findings suggested that digital transformation could indeed enhance overall enterprise productivity.

Table 1. Benchmark regression results.

	(1) TFP	(2) TFP	(3) TFP	(4) TFP
Digital	0.0022***	0.0037***	0.0030***	0.0012***
	(0.0003)	(0.0005)	(0.0002)	(0.0003)
SIZE			0.5534***	0.5268***
			(0.0040)	(0.0171)
AGE			-0.0287	0.4141
			(0.0225)	(1.1555)
SOE			-0.0192**	-0.0123
			(0.0095)	(0.0342)
TOP1			0.0011***	-0.0015
			(0.0003)	(0.0010)
INDBR			-0.0003	-0.0003
			(0.0008)	(0.0011)
CASH			-0.0169***	-0.0158***
			(0.0032)	(0.0038)
ROA			2.9809***	2.1317***
			(0.0815)	(0.1114)
LEV			1.1287***	0.4693***
			(0.0306)	(0.0611)
_cons	8.4630***	8.4452***	-4.4607***	-4.8749
	(0.0081)	(0.0054)	(0.1148)	(3.7595)
Enterprise/Year Fixed	No	Yes	No	Yes
N	19934	19934	19927	19927
R^2	0.0033	0.8839	0.6938	0.9310

Note: "***","**", and "*" indicate that they are displayed at the significance level of "1%","5%", and "10%" respectively. The data in parentheses are the standard error of enterprise-level clustering. The tables below are identical.

4.2 Robustness Test

Replacement of core variables: This study used different word frequency construction methods (Digital_1, Digital_2) to re-measure the digital transformation indicators, and found that the regression results were consistent with the findings of the benchmark regression.

Replacement of explanatory variables: This study used the OP method to recalculate TFP, and the results still supported the facilitating role of digital transformation.

Adjusting the clustering hierarchy: After this study clustered the standard errors to the industry-time dimension, the significance of Digital was not affected (Table 2).

Table 2. Replace Digital_1, Digital_2, and Digital regression results.

	Digital_1 TFP(1)	Digital_1 TFP(2)	Digital_2 TFP(1)	Digital_2 TFP(2)	Digital TFP_OP (1)	Digital TFP_OP (2)	Digital TFP(1)	Digital TFP(2)
	0.0022***	0.0007***	0.0021***	0.0007***	0.0026***	0.0008**	0.0037***	0.0013**
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0004)	(0.0003)	(0.0010)	(0.0005)
Control variable	No	Yes	No	Yes	No	Yes	No	Yes
Enterprise/Year Fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.4093***	-4.5438	8.4450***	-4.6651	6.7525***	-2.2690	8.4452***	-3.5810***
	(0.0085)	(3.7793)	(0.0050)	(3.7705)	(0.0049)	(2.8456)	(0.0131)	(0.3288)
N	19934	19927	19934	19927	19934	19927	19934	19934
R^2	0.8849	0.9311	0.8837	0.9310	0.8587	0.8994	0.8839	0.9307

4.3 Endogenous Treatment

Additional control variables, such as liquidity ratio and Tobin's Q, were included in the analysis. The core findings remained robust after their introduction (Table 3).

Employing the instrumental variable method, with the mean of digital transformation within the corresponding industry as the instrumental variable, the two-stage least squares (2SLS) regression demonstrated that digital transformation still significantly enhanced TFP, mitigating the issue of reverse causality (Table 4).

In conclusion, the empirical outcomes validated that digital transformation had the potential to enhance the TFP of enterprises, with a strong and consistent conclusion.

Table 3. Further adding control variable baseline regression results.

	(1) TFP	(2) TFP	(3) TFP	(4) TFP
Digital	0.0037***	0.0012***	0.0012***	0.0012***
	(0.0005)	(0.0003)	(0.0003)	(0.0003)
SIZE		0.5268***	0.5266***	0.5383***
		(0.0171)	(0.0171)	(0.0174)
AGE		0.4141	0.4747	0.6419
		(1.1555)	(1.1532)	(1.1516)
SOE		-0.0123	-0.0131	-0.0094
		(0.0342)	(0.0341)	(0.0338)
TOP1		-0.0015	-0.0015	-0.0013
		(0.0010)	(0.0010)	(0.0010)
INDBR		-0.0003	-0.0003	-0.0004
		(0.0011)	(0.0011)	(0.0011)
CASH		-0.0158***	-0.0232**	-0.0221**
		(0.0038)	(0.0071)	(0.0071)
ROA		2.1317***	2.1369***	2.0369***
		(0.1114)	(0.1115)	(0.1132)
LEV		0.4693***	0.4880***	0.4718***
		(0.0611)	(0.0646)	(0.0648)
Liquidity			0.0061	0.0063
			(0.0053)	(0.0053)
Tobin_Q				0.0267***
				(0.0048)
_cons	8.4452***	-4.8749	-5.0816	-5.9324
	(0.0054)	(3.7595)	(3.7535)	(3.7494)
N	19934	19927	19927	19927
R^2	0.8839	0.9310	0.9310	0.9313

Table 4. Regression results for endogenous problems.

	(1) first stage Digital	(2) second stage TFP
Digital		0.0176***
		(0.002)
IV	8.1131***	
	(0.499)	
SIZE	8.0026***	0.3923***
	(0.306)	(0.014)
AGE	-67.0738	1.4993
	(81.575)	(1.996)
SOE	-0.5215	-0.0078
	(0.806)	(0.020)

TOP1	-0.1079***	0.0004
	(0.019)	(0.000)
INDBR	-0.0933***	0.0014*
	(0.032)	(0.001)
CASH	-1.6427***	0.0113***
	(0.103)	(0.004)
ROA	-23.9028***	2.5509***
	(2.624)	(0.075)
LEV	-8.2124***	0.6112***
	(1.366)	(0.036)
Constant	49.4019	-5.4760
	(297.061)	(7.260)
Observations	19，927	19，927
R-squared	0.736	0.882

5 Mechanism of Action Tests

Columns (1)-(3) showed the test results with ESG as the mediating variable, where the Digital Transformation Index in column (1) was significantly positive at the 1% level (Table 5). The analysis revealed that digital transformation improved the TFP of enterprises by enhancing ESG performance, thereby verifying hypothesis H2.

Table 5. Mediating effects regression results.

	(1) TFP	(2) ESG	(3) TFP
Digital	0.0036***	0.0083***	0.0035***
	(0.0004)	(0.0025)	(0.0004)
ESG			0.0071***
			(0.0011)
Control variable	Yes	Yes	Yes
Enterprise/Year Fixed	Yes	Yes	Yes
_cons	5.7706	115.8095	4.9470
	(5.1501)	(72.5888)	(5.0377)
N	19927	19927	19927
R^2	0.9026	0.5277	0.9031

6 Heterogeneity Analysis

The impact of Supply Chain Finance on digital transformation and enterprise productivity from an enterprise perspective may vary depending on the size and ownership structure of the enterprise. Thus, the following discussion delves into the heterogeneity based on two aspects.

6.1 Enterprise Size

The median enterprise size for the year served as the threshold for this classification; enterprises equal to or exceeding the median size were classified as large-scale, while those below it were considered small and medium-sized. Table 5 showed that the coefficients for digital transformation in small and medium-sized enterprises were consistently positive. Moreover, these coefficients tended to be higher for small and medium-sized enterprises than for large-scale enterprises. This observation suggested that digital transformation played a crucial role in enhancing enterprise productivity, thereby corroborating previous findings. Notably, the impact of digital transformation is more pronounced in small and medium-sized enterprises, which often face challenges related to limited access to financing and high financing costs. Hence, it was essential to consider the unique characteristics and requirements of businesses of varying scales when implementing digital transformation, and to customize solutions that aligned with their growth objectives (Table 6).

Table 6. Heterogeneous firm size regression results.

	(1) large-scale enterprise	(2) small and medium-sized enterprises	(3) large-scale enterprise	(4) small and medium-sized enterprises
Digital	0.0021***	0.0029***	0.0009*	0.0011**
	(0.0006)	(0.0005)	(0.0005)	(0.0004)
SIZE			0.4902***	0.5379***
			(0.0278)	(0.0242)
AGE			1.4806	0.8184
			(1.5370)	(1.6946)
SOE			-0.0200	-0.0128
			(0.0447)	(0.0459)
TOP1			-0.0020*	-0.0019
			(0.0011)	(0.0015)
INDBR			0.0004	0.0000
			(0.0014)	(0.0017)
CASH			-0.0205	-0.0104**
			(0.0127)	(0.0041)
ROA			2.7300***	1.6370***
			(0.1872)	(0.1226)
LEV			0.3334**	0.5235***
			(0.1039)	(0.0732)
_cons	9.1329***	7.7886***	-7.3562	-6.5025
	(0.0063)	(0.0063)	(5.0820)	(5.4644)
N	9906	9916	9899	9916
R^2	0.8921	0.7876	0.9253	0.8525

6.2 Nature of Enterprise Ownership

The influence of business ownership on digital transformation effectiveness was examined in terms of state-owned enterprises and non-state-owned enterprises. State-owned enterprises were coded as 1, while non-state-owned enterprises were coded as 0. Analysis of regression results indicated that the coefficient for state-owned business was not statistically significant, whereas the coefficient for non state-owned business was significant. This suggested that digital transformation contributed more significantly to enhancing total factor productivity growth in non-state-owned enterprises. Thus, it could be inferred that different ownership types responded differently to digital transformation initiatives. State-owned enterprises typically exhibited greater operational efficiency and stability in liquidity and management processes compared to non-state-owned enterprises (Table 7).

Therefore, the promotion effect of digital transformation on TFP of enterprises was heterogeneous, which verified hypothesis H3.

Table 7. Heterogeneous regression results of enterprise ownership properties.

	(1)	(2)	(3)	(4)
	SOE=1	SOE=0	SOE=1	SOE=0
Digital	0.0032**	0.0034***	0.0005	0.0012***
	(0.0010)	(0.0005)	(0.0007)	(0.0003)
SIZE			0.4731***	0.5386***
			(0.0304)	(0.0202)
AGE			0.5431	0.0892
			(1.3594)	(1.6390)
TOP1			0.0013	-0.0030**
			(0.0016)	(0.0013)
INDBR			0.0009	-0.0002
			(0.0015)	(0.0016)
CASH			-0.0196*	-0.0132**
			(0.0105)	(0.0041)
ROA			3.0314***	1.8450***
			(0.1984)	(0.1259)
LEV			0.5196***	0.4357***
			(0.1115)	(0.0704)
_cons	8.8106***	8.1870***	-4.2514	-4.0565
	(0.0075)	(0.0076)	(4.5436)	(5.2403)
N	8383	11522	8376	11522
R^2	0.9098	0.8557	0.9416	0.9166

7 Conclusion

Based on the data of A-share listed companies in Shanghai and Shenzhen from 2009 to 2022, this paper discussed the impact of enterprise digital transformation on TFP, and analyzed the value creation mechanism through the mechanism. Research showed that:

Digital transformation has greatly enhanced the TFP of enterprises. Even after carefully accounting for potential endogeneity resulting from potential reverse causality among variables, the findings from the benchmark regression remain robust when substituting explanatory variables and core explanatory variables. This further confirms the reliability of the conclusion.

Digital transformation enhances TFP in enterprises by optimizing ESG performance. It facilitates precise monitoring and reporting of environmental and social contributions, enhancing transparency of environmental information, and thereby improving ESG performance. The impact of digital transformation on TFP exhibits notable diversity. In terms of firm size, small and medium-sized enterprises experience a more pronounced enhancement in TFP due to digital transformation compared to large enterprises. Similarly, concerning ownership structure, non-state-owned enterprises demonstrate a more substantial increase in TFP as a result of digital transformation.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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