

The Impact of Corporate Digital Transformation on Innovation Efficiency: Evidence from Chinese Listed Companies

Binyang Gong*

College of Transport & Communications, Shanghai Maritime University, Shanghai 201306, China

**Corresponding author: Binyang Gong.*

Abstract

Innovation is an important factor affecting the sustainable competitiveness of enterprises, but many enterprises face the problem of low innovation efficiency, and digital technology provides a path to improve the innovation efficiency of enterprises. Based on the data of China's A-share listed companies from 2012 to 2022, this article explores the impact of enterprise digital transformation on innovation efficiency and its mechanism. The study found that digital transformation can improve the innovation efficiency of enterprises, and this conclusion is still valid after passing a series of robustness tests; Mechanism analysis shows that the corporate digital transformation can alleviate financing constraints and enhance total factor productivity, thus improving the innovation efficiency of enterprises; Heterogeneity analysis shows that this effect is more prominent in state-owned enterprises, large-scale enterprises, mature enterprises and highly competitive industries. This article expands the study of the economic consequences of digital transformation from the perspective of innovation efficiency, and provides empirical evidence and policy implications for enterprises to promote digital strategies and improve the efficiency of innovative resource allocation.

Keywords

digital transformation, innovation efficiency, financing constraints, total factor productivity (TFP)

1. Introduction

Innovation is the first driving force to lead development, and it is also the core source for enterprises to gain competitive advantages and achieve sustainable development. As the main body of micro-innovation, the efficiency of an enterprise's innovation activities directly determines its market competitiveness. However, for a long time, many enterprises have faced the problem of high R&D investment and low innovation output. Although the investment in research and development funds of the whole society continues to grow, the innovative results produced by the unit input have not increased in the same proportion, and the mismatch and waste of innovative resource allocation are still prominent. At the same time, the global competition in science and technology is intensifying. How to effectively improve the efficiency of enterprise innovation and achieve

innovation breakthroughs under the constraints of limited resources has become an important problem that needs to be solved urgently.

The booming development of the digital economy provides new solutions to the above problems. Digital technology represented by big data, cloud computing, artificial intelligence, blockchain, etc. is profoundly reshaping the operation mode and competitive logic of enterprises. Digital transformation has become a strategic choice for enterprises to conform to the changes of the times. At present, studies have explored the economic effects of digital transformation from multiple angles, such as its positive impact on industrial upgrading, supply chain coordination and corporate governance; In the field of innovation, research has found that digital transformation can promote firms' innovation output. However, most of the existing literature focuses on the pull of digital transformation on quantity, and few studies systematically examine its impact on innovation efficiency and its inherent transformation path.

In order to make up for the above shortcomings, this article systematically examines the impact of enterprise digital transformation on innovation efficiency and its mechanism based on the resource-based theory. Specifically, this article first tests whether digital transformation can directly improve the innovation efficiency of enterprises; Secondly, from the two paths of financing constraint relief and total factor productivity improvement, the indirect transmission mechanism of digital transformation affecting innovation efficiency is revealed; Thirdly, analyze the heterogeneity characteristics of the above influence from the four dimensions of property rights, enterprise scale, enterprise age and industry competition. The study uses the data of China's A-share listed companies from 2012 to 2022, and uses the two-way fixed effect model for empirical testing, in order to provide reliable empirical evidence for understanding the effect of digital transformation on innovation efficiency.

The research contribution of this article is mainly reflected in three aspects. First, unlike the existing literature, which mainly focuses on the impact of digital transformation on the number of innovation outputs, this article analyzes the efficiency of innovation, clarifies the output changes brought about by the R&D investment of units, and reflects whether digital transformation improves the efficiency of innovation, rather than just expanding the scale of innovation. Second, under the framework of resource-based theory, this paper also tests the two intermediary paths of financing constraints and total factor productivity, and reveals the transformation mechanism of digital transformation affecting innovation efficiency. Third, this article conducts group tests from the four dimensions of property rights, enterprise scale, enterprise age and industry competition, and finds that there are obvious differences in the innovation efficiency improvement effect of digital transformation between different types of enterprises. This result provides a reference for policymakers to design differentiated digital support policies for different enterprise groups, and for enterprise managers to formulate digital strategies according to their own conditions.

2. Literature Review and Research Hypotheses

2.1 The Effects of Corporate Digital Transformation

As a product of the deep integration of a new generation of information technology and the real economy, digital transformation is changing the operation mode, organizational structure and competition pattern of enterprises. Existing studies have investigated the economic consequences of the digital transformation of enterprises, and found that the digital transformation of enterprises has an impact on industrial structure, enterprise production and operation, management decision-making and innovation activities. Specifically, Huang Qunhui et al. (2019) found that digital transformation can promote industrial upgrading and optimize resource allocation efficiency [1]; Digital transformation can alleviate the problem of information asymmetry in enterprise operations and improve the efficiency of supply chain coordination [2]; Qi Huaijin et al. (2020) analyzed from the perspective of corporate governance and found that digital transformation can optimize the internal governance mechanism of enterprises and reduce agency costs. [3]

For the innovation field focused on in this article, research shows that digital transformation can promote the innovation output of enterprises, but there is still room for further discussion on its impact mechanism on innovation efficiency [4]. In general, the existing literature affirms the multi-dimensional impact of digital transformation on enterprise behavior, but it still needs to be analyzed in depth in combination with theoretical

mechanisms and empirical evidence on how it systematically affects the efficiency of enterprise innovation and through which this effect operates.

2.2 Determinants of Corporate Innovation Efficiency

The innovation efficiency of enterprises reflects the level of innovation output brought about by the innovation input of the unit, which is an important indicator to measure the innovation effect of enterprises. Studies have examined the influencing factors of corporate innovation efficiency from the two levels of internal governance and external environment. In terms of internal factors, Feng Genfu and Wen Jun (2008) confirmed that enterprise scale, capital structure, equity structure, executive team characteristics, corporate governance level, etc. all have a significant impact on innovation efficiency [5]; At the same time, Lu Xiaodong and Lian Yujun (2012) also believe that the total factor productivity of enterprises is closely related to innovation efficiency as a comprehensive indicator reflecting the ability of resource allocation and the level of technological progress [6]. External factors mainly include financing environment, market competition, industrial policies, intellectual property protection, etc. Specifically, financing constraints are a key obstacle to the improvement of innovation efficiency of enterprises, because innovation activities have the characteristics of long cycle, high risk, serious information asymmetry, etc. External financing difficulties will directly limit the sustainability and scale of enterprise R&D investment [7]. In recent years, with the development of the digital economy, scholars have begun to pay attention to the impact of digital economy, information technology and AI tools on enterprise innovation and its innovation efficiency, which provides an important theoretical foundation for this research.

2.3 Theoretical Analysis and Research Hypotheses

The resource-based theory believes that enterprises are a collection of heterogeneous resources, and the continuous competitive advantage comes from their valuable, scarce, inimitable and irreplaceable strategic resources. Digital transformation has injected new intangible resources such as data assets, digital platforms and algorithmic capabilities into enterprises. These resources are highly synergistic and reconfigurable, and can reshape the knowledge integration, process management and market perception capabilities of enterprises. Based on this theory, this article systematically demonstrates the mechanism of the impact of digital transformation on innovation efficiency.

(1) The impact of enterprise digital transformation on innovation efficiency

The resource-based theory points out that the competitive advantage of an enterprise comes from its unique strategic resources. The data, platform and algorithm capabilities injected by digital transformation are synergistic and reconfiguring. On the one hand, these resources break down information silos and accelerate the integration and reorganization of knowledge; On the other hand, optimize process management and reduce coordination costs; At the same time, with the help of big data analysis, we can accurately locate market opportunities and reduce R&D decision-making errors. Multiple effects make innovation output higher under the same input, which directly improves innovation efficiency. Therefore, this article puts forward hypothesis 1:

H₁: The digital transformation of enterprises can improve the innovation efficiency of enterprises.

(2) The Mediating Role of Financing Constraints

The resource-based theory points out that the strategic value of resources also lies in improving the conditions for obtaining external resources. Digital infrastructure improves the transparency and standardization of enterprise information, reduces the cost of information acquisition and supervision for external investors, and effectively alleviates financing constraints. After the financing constraints are eased, the R&D capital guarantee is more sufficient, the allocation is more optimized, the innovation activities continue to be stable, and the unit input and output are higher. Accordingly, it is proposed hypothesis 2:

H₂: The digital transformation of enterprises can ease the financing constraints of enterprises, so as to improve the innovation efficiency of enterprises.

(3) The Mediating Role of Total Factor Productivity

The theory believes that new resources can reshape the production function. Digital resources are embedded in the production process, promote automation and collaborative optimization, and significantly improve total factor productivity (TFP). TFP promotion not only enhances the ability of knowledge absorption and R&D transformation, but also improves profitability and cash flow, and provides stable endogenous funds for innovation. The two jointly promote the efficiency of innovative output. Based on this, hypothesis 3 is put forward:

H₃: The digital transformation of enterprises can improve the total factor productivity (TFP) of enterprises, thus improving the innovation efficiency of enterprises.

3. Research Design

3.1 Sample Selection and Data Sources

This article selects the data of Chinese A-share listed companies from 2012 to 2022 for empirical research. This article pre-processed the data as follows: (1) eliminate the samples of the financial industry; (2) eliminate the samples of enterprises marked as ST, *ST and missing key variables; (3) In order to avoid the potential interference of extreme values, the continuous variables should be reduced at the level of 1% before and after. Finally, 29824 observations were obtained. The full text of the original data at the enterprise level comes from the CSMAR database.

3.2 Model Specification

In order to test the impact of digital transformation on the innovation efficiency of enterprises, this paper constructs an enterprise-year two-way fixed effect model:

$$InnoEFF_{i,t} = \alpha_0 + \alpha_1 Digital_{i,t} + \alpha_2 Contrls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

Among them, *i* represents the enterprise and *t* represents the year. Among them, *InnoEff_{it}* is the dependent variable corporate innovation efficiency, *Digital_{it}* is the core explanatory variable enterprise digital transformation, *Contrls_{it}* is a series of control variables, μ_i indicating the individual fixed effect of the enterprise, δ_t indicating the fixed effect of the year, and ε_{it} is a random disturbance term. This article uses the enterprise-level clustering standard error.

3.3 Variable Measurement

(1) Dependent variables. The dependent variable in this article is corporate innovation efficiency (*InnoEff*). Refer to the existing literature, and use the number of patent applications produced by the unit's R&D investment as a comprehensive agent indicator of innovation efficiency.

(2) Core explanatory variable. This article refers to the research method of Wu Fei et al. (2021) to portray the level of digital transformation of enterprises based on the frequency of digital keywords in the annual reports of listed companies [8]. The specific construction process is as follows: First, manually collect and sort out the annual report texts of all observed enterprises; Secondly, identify 23 digital-related keywords, covering digital, big data, blockchain, cloud computing, artificial intelligence, Internet of Things, machine learning and other terms; Finally, the text analysis software is used to count the frequency of occurrence of the above words enterprise by enterprise. In order to reduce statistical errors, the method of firm-level textual analysis is adopted, and the total number of word frequency is added by 1 and the natural logarithm is taken as a proxy variable of the degree of digital transformation of the enterprise.

(3) Control variables. To control for the influence of other factors on corporate technological innovation efficiency, this study draws on the research of Wu et al. (2021) and selects the following variables as controls: firm size (*Size*), leverage ratio (*Leverage*), shareholding ratio of the largest shareholder (*Top1*), ownership nature (*Ownership*), revenue growth rate (*Growth*), board independence (*Director*), and return on assets (*ROA*). The specific measurements of these variables are presented in Table 1.

The descriptive analysis results of the main variables in this article are shown in Table 2, and the sample contains a total of 29,824 observations. The average value of the corporate innovation efficiency (*InnoEff*) of the dependent variable is 16.828, the standard deviation is 8.193, the minimum value is 0, the median is 17.899,

and the maximum value is 33.730, indicating that there is a large difference in the innovation efficiency of the sample enterprise. The mean value of the core explanatory variable Digital is 3.125, the standard deviation is 1.228, the value range is from 0 to 5.927, and the median is 3.091, indicating that the sample enterprises are moderately dispersed in the degree of digital transformation. The descriptive statistical results of the remaining control variables are shown in Table 2.

Table 1: Variable Definitions and Measurements

VarName	Measurement
InnoEff	$\ln(\text{Total number of patent applications in the current year} + 1) / \ln(\text{R\&D expenditure in the current year} + 1)$
Digital	$\ln(\text{Total keyword frequency} + 1)$
lnage	$\ln(\text{Observation year} - \text{year of establishment} + 1)$
Leverage	Total liabilities / Total assets
top1	Number of shares held by the largest shareholder / Total share capital
Ownership	Nature of the ultimate controlling shareholder in the current year
Growth	Percentage growth in operating revenue relative to the previous year
Director	$\ln(\text{Number of independent directors} + 1)$
roa	Net profit / Total assets

Table 2: Descriptive Statistics

VarName	Obs	Mean	SD	Min	Median	Max
InnoEff	29824	16.828	8.193	0	17.899	33.730
Digital	29824	3.125	1.228	0	3.091	5.927
size	29824	22.172	1.285	19.971	21.961	26.269
lnage	29824	1.981	0.925	0	2.079	3.332
Leverage	29824	0.406	0.202	0.055	0.393	0.914
top1	29824	0.337	0.145	0.087	0.314	0.731
Ownership	29824	0.308	0.462	0.000	0.000	1.000
Growth	29824	0.302	0.699	-0.682	0.128	4.411
Director	29824	1.409	0.122	1.099	1.386	1.792
roa	29824	0.037	0.069	-0.304	0.039	0.206

4. Empirical Results

4.1 Baseline Regression Results

The results of the baseline regression of digital transformation to the innovation efficiency of enterprises are shown in Table 3. Column (1) is the result of ordinary OLS regression, column (2) adds fixed effects, column (3) adds control variables on the basis of column (1), and column (4) is the result of adding all control variables under a two-way fixed effect. Column (4) shows that the estimated coefficient of the core explanatory variable enterprise digital transformation on corporate innovation efficiency is 0.340, and it is significantly positive at the level of 1%, which verifies hypothesis 1.

4.2 Robustness Tests

In order to test the robustness of the research conclusion, this paper adopts five methods for re-estimation: replacing the dependent variable, lagging the explanatory variable by one period, replacing the time interval, adding high-dimensional fixed effects, and using the Tobit model. The specific results are as follows:

(1) Replace the dependent variable. In order to avoid interference with the benchmark conclusion by different measurement methods of innovation efficiency, the original dependent variable InnoEff is replaced with $\text{InnoEff2} = \ln(\text{enterprise's invention patent application volume} + 1) / \ln(\text{enterprise's R\&D expenditure} + 1)$ to return. As shown in column (1) of Table 4, the estimated coefficient of Digital is 0.003, which is significantly positive at the level of 1%. It shows that the effect of digital transformation on the innovation efficiency of enterprises does not depend on the specific measurement of innovation efficiency, and the results remain robust.

(2) Explain that the variable lags back one period. In order to alleviate the endogenous problems caused by reverse causality, the core explanatory variable one-period lagged Digital (L.Digital) is included in regression. As shown in column (2) of Table 4, the estimated coefficient of L.Digital is 0.315, which is significantly

positive at the level of 1%, indicating that the promotion of digital transformation has a duration and alleviates the interference of reverse causality to the baseline conclusion.

Table 3: Baseline Regression Results

	(1)	(2)	(3)	(4)
	InnoEff	InnoEff	InnoEff	InnoEff
Digital	1.289***	0.641***	1.115***	0.340***
	(34.017)	(7.898)	(30.485)	(4.431)
size			2.270***	2.343***
			(48.769)	(15.372)
lnage			-0.561***	0.301**
			(-9.423)	(1.995)
Leverage			1.249***	-1.081**
			(4.468)	(-2.112)
topl			-1.913***	1.763*
			(-5.901)	(1.909)
Ownership			-0.021	0.264
			(-0.181)	(0.874)
Growth			-0.411***	-0.046
			(-6.517)	(-0.670)
Director			-0.660*	0.420
			(-1.710)	(0.644)
roa			7.251***	1.109
			(10.090)	(1.571)
cons	12.800***	14.826***	-34.938***	-37.629***
	(100.618)	(58.482)	(-36.618)	(-11.033)
Firm FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES
N	29824	29824	29824	29824
r2	0.037	0.725	0.157	0.735

Note: *t*-statistics are reported in parentheses. Standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The same notation applies hereafter.

Table 4: Robustness Test Results

	(1)	(2)	(3)	(4)	(5)	(6)
	InnoEff2	InnoEff	InnoEff	InnoEff	InnoEff	InnoEff
Digital	0.003***		0.199**	0.396***	0.337***	1.170***
	(4.497)		(2.150)	(5.402)	(4.478)	(13.978)
L.Digital		0.315***				
		(3.980)				
size	0.025***	2.271***	2.293***	2.486***	2.397***	2.397***
	(18.011)	(13.992)	(11.268)	(16.690)	(15.582)	(20.964)
lnage	0.001	-0.057	0.460**	0.441***	0.398***	-0.633***
	(0.364)	(-0.223)	(2.142)	(2.921)	(2.586)	(-4.971)
Leverage	-0.011**	-1.028*	-0.337	-0.641	-1.155**	1.137*
	(-2.528)	(-1.916)	(-0.495)	(-1.333)	(-2.261)	(1.737)
topl	0.010	1.498	2.186*	1.020	1.647*	-2.204***
	(1.153)	(1.530)	(1.866)	(1.179)	(1.784)	(-2.753)
Ownership	0.001	0.104	0.328	0.310	0.293	-0.020
	(0.407)	(0.344)	(0.699)	(1.095)	(0.972)	(-0.070)
Growth	-0.001	0.027	-0.090	-0.031	-0.033	-0.453***
	(-0.808)	(0.381)	(-1.031)	(-0.464)	(-0.486)	(-3.734)
Director	0.003	0.188	0.651	0.858	0.522	-0.681
	(0.546)	(0.273)	(0.828)	(1.412)	(0.814)	(-0.758)
roa	0.004	1.062	2.391**	1.345*	1.098	7.935***
	(0.558)	(1.507)	(2.366)	(1.920)	(1.567)	(6.417)
cons	-0.457***	-34.548***	-37.811***	-41.833***	-39.100***	-37.914***
	(-14.725)	(-9.505)	(-8.426)	(-12.625)	(-11.473)	(-16.094)
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
IndxYear FE	NO	NO	NO	YES	NO	NO

ProxYear FE	NO	NO	NO	NO	YES	NO
N	29416	24931	18217	29750	29819	29824
r2	0.743	0.747	0.748	0.752	0.741	

(3) Change the time interval. Considering the external impact of the epidemic in 2020, the sample is limited to re-estimated before 2020. The results are shown in column (3) of Table 4. The estimated coefficient of Digital is 0.199, which is significantly positive at the level of 1%, which is consistent with the benchmark conclusion, indicating that the research conclusion is not interfered by a specific time window.

(4) High-dimensional fixed effect model. In order to avoid the causal identification of time, industry, region and other factors interfering with the efficiency of digital transformation and technological innovation, the interactive fixed effect of industry and year and the interactive fixed effect of province and year are studied respectively. As shown in columns (4) and (5) of Table 4, the estimated coefficients of Digital are 0.396 and 0.337 respectively, both of which are significantly positive at the 1% level, indicating that after excluding the time-changing and unobservable factors at the industry and regional levels, the positive impact of digital transformation on innovation efficiency is still stable.

(5) Use the Tobit model. Since the innovation efficiency of the dependent variable is a continuous variable truncated to 0 on the left, the panel Tobit model is used for estimation. As shown in column (6) of Table 4, the estimated coefficient of Digital is 1.170, which is significantly positive at the 1% level, which further verifies the reliability of the baseline regression results.

4.3 Mechanism Analysis

It has been verified above that the digital transformation of enterprises has a significant positive impact on innovation efficiency, but the path of this impact still needs to be further tested. In order to reveal the inherent mechanism of digital transformation to improve innovation efficiency, this paper tests the mechanism from the two paths of financing constraint relief and total factor productivity improvement respectively.

(1) Financing Constraints (WW)

According to the previous analysis, digital transformation can alleviate the constraints of enterprise financing through information sharing and reducing transaction costs, thereby providing financial support for innovation activities and improving innovation efficiency. This article refers to the research of Lu Yuan and Wang Yang (2023) to measure the financing constraints of enterprises with the WW index. The relevant regression results are shown in column (1) of Table 5. The estimated coefficient of Digital is -0.002, which is significantly negative at the level of 1%, indicating that the digital transformation has significantly eased the financing constraints, thereby reducing the premium cost of external financing of enterprises and the risk of information asymmetry, so that long-term research and development projects that were originally suppressed by lack of funds can obtain sustained financial support, so as to effectively respond to fluctuations in innovation investment and improve innovation efficiency, and supporting the hypothesis 2 of this article.

(2) Total factor productivity (TFP)

The total factor productivity of an enterprise comprehensively reflects the efficiency of resource allocation, technology absorption capacity and production and operation efficiency. Digital transformation empowers digital technology to optimize production processes and organizational coordination, so as to improve total factor productivity (TFP); The improvement of total factor productivity can release more resources for innovation activities and promote the improvement of innovation efficiency. The regression results in column (2) of Table 5 show that the estimated coefficient of Digital is 0.021, which is significantly positive at the 1% level. The result shows that digital transformation can improve total factor productivity (TFP), thereby optimizing factor allocation and releasing internal cash flow, so that R&D investment can obtain more abundant financial security, while reducing the adjustment and trial and error loss of the innovation process, and ultimately improving innovation efficiency, which verifies the hypothesis 3 of this article.

4.4 Heterogeneity Analysis

In order to test whether there are differences in the impact of digital transformation on the innovation efficiency of enterprises under different situations, this article analyzes the heterogeneity of digital

transformation on the innovation efficiency of enterprises from the four dimensions of property rights, enterprise scale, enterprise age and industry competition.

Table 5: Mechanism Analysis Results

	(1)	(2)
	WW	TFP
Digital	-0.002***	0.021***
	(-4.157)	(3.602)
size	-0.055***	0.729***
	(-68.479)	(47.321)
lnage	0.006***	0.033**
	(6.597)	(1.999)
Leverage	0.012***	0.355***
	(3.523)	(7.282)
top1	-0.030***	-0.017
	(-5.932)	(-0.221)
Ownership	0.003	-0.035
	(1.408)	(-1.524)
Growth	-0.007***	-0.030***
	(-9.039)	(-5.103)
Director	0.002	0.086*
	(0.439)	(1.820)
roa	-0.209***	1.586***
	(-33.069)	(21.298)
cons	0.202***	-6.006***
	(11.583)	(-17.234)
Firm FE	YES	YES
Year FE	YES	YES
N	24803	27026
r2	0.866	0.958

(1) The nature of property rights

There are systematic differences between state-owned and non-state-owned enterprises regarding resource acquisition, organizational structure, and policy support. In this study, the sample is divided into a state-owned enterprise group (Ownership = 1) and a non-state-owned enterprise group (Ownership = 0) based on the nature of the ultimate controller. The results of the subgroup regression are presented in columns (1) and (2) of Table 6; the effect of digital transformation is more significant in the state-owned enterprise group, and there is a difference between the groups. The reason lies in the fact that state-owned enterprises (SOEs)—leveraging advantages in capital, organization, and policy—can more easily integrate digital technologies into their existing systems and unlock greater innovation dividends; in contrast, while non-state enterprises benefit from flexible mechanisms, their resource constraints result in relatively weaker performance improvements.

(2) Enterprise scale

There is a big difference between large-scale enterprises and small-scale enterprises in terms of capital strength, talent reserve and risk tolerance. This paper divides the samples into small-scale enterprise groups and large-scale enterprise groups according to the annual median of the total assets of the enterprise. The regression results are shown in Column (3) and Column (4) of Table 6, and digital transformation is more prominent in large-scale enterprise groups. This result shows that large-scale enterprises have stronger financial support and professional and technical talent reserves, can undertake the high early investment in the construction of digital systems, and realize the deep integration of digitalization with R&D, production and management, so as to more effectively transform digital capabilities into the improvement of innovation efficiency.

(3) Age of the enterprise

The establishment period of an enterprise comprehensively reflects the differences in industry experience, customer accumulation, standardized management process and resource accumulation of the enterprise. This article divides the sample into young enterprise group and mature enterprise group according to the median annual number of years of establishment of the enterprise. As shown in columns (5) and (6) of Table 6, digital transformation is more prominent in mature enterprise groups. This shows that mature enterprises have accumulated rich industry experience, stable customer relationships and standardized management processes. Digital tools can complement their existing advantages and produce stronger synergy through process reengineering and knowledge integration.

(4) The degree of competition in the industry

There is a significant difference between high-competition and low-competition industries in external pressure and innovation incentives, which may affect the transformation effect of digital transformation on innovation efficiency. This article uses the Herfindahl Index (HHI) to measure the degree of competition in the industry. According to the annual industry medium, the sample is divided into high-competitive group and low-competitive group. As shown in Columns (7) and Columns (8) of Table 6, the regression results show that digital transformation is more prominent in the high-competition group. This reflects the great pressure to survive in high-competition industries, forcing enterprises to deeply apply digital technology, and the improvement of innovation efficiency is more obvious; the low-competition industry lacks motivation and weak effect.

Table 6: Heterogeneity Analysis Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Non-SOEs	SOEs	Smaller Firms	Larger Firms	Younger Firms	Older Firms	Less Competitive Markets	More Competitive Markets
	InnoEff	InnoEff	InnoEff	InnoEff	InnoEff	InnoEff	InnoEff	InnoEff
Digital	0.488***	0.229**	0.206*	0.358***	0.191*	0.385***	0.256**	0.373***
	(3.647)	(2.535)	(1.945)	(3.218)	(1.938)	(3.457)	(2.266)	(3.707)
size	2.634***	2.261***	3.258***	2.375***	2.521***	2.248***	2.273***	2.401***
	(9.695)	(11.909)	(11.968)	(9.952)	(10.055)	(10.254)	(10.405)	(10.687)
lnage	0.130	0.899***	0.372*	-0.401	0.726***	-3.672***	0.373	0.333
	(0.355)	(5.089)	(1.770)	(-1.335)	(3.081)	(-2.897)	(1.628)	(1.520)
Leverage	-0.154	-1.549***	-1.085	-1.303	-0.973	0.137	-0.415	-1.350**
	(-0.149)	(-2.627)	(-1.593)	(-1.540)	(-1.403)	(0.180)	(-0.562)	(-2.019)
top1	-2.323	3.359***	3.417**	0.495	4.011***	-1.171	1.479	3.038**
	(-1.460)	(2.869)	(2.299)	(0.406)	(2.627)	(-0.897)	(1.093)	(2.538)
Ownership	/	/	-0.586	0.819**	-0.371	1.040**	0.332	0.060
	/	/	(-1.219)	(2.036)	(-0.709)	(2.576)	(0.771)	(0.153)
Growth	0.144	-0.188**	-0.085	0.079	-0.139	0.050	-0.020	-0.091
	(1.439)	(-2.083)	(-0.924)	(0.795)	(-1.449)	(0.548)	(-0.199)	(-0.942)
Director	-0.509	1.104	0.834	0.143	0.926	0.031	0.506	0.446
	(-0.433)	(1.461)	(0.866)	(0.157)	(1.014)	(0.033)	(0.571)	(0.513)
roa	0.149	0.889	0.000	1.488	1.043	0.690	1.168	0.731
	(0.106)	(1.078)	(0.000)	(1.219)	(0.934)	(0.769)	(1.162)	(0.696)
cons	-42.663***	-37.282***	-57.331***	-36.393***	-42.211***	-24.894***	-36.735***	-38.916***
	(-6.668)	(-8.892)	(-9.888)	(-6.440)	(-7.590)	(-4.048)	(-7.662)	(-7.867)
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
N	9134	20624	14698	14711	15189	14501	14494	14376
r2	0.769	0.723	0.708	0.770	0.763	0.758	0.759	0.749

5. Conclusion

Based on the data of Chinese A-share listed companies from 2012 to 2022, this article studies the impact of enterprise digital transformation on innovation efficiency and its mechanism. The study found that digital transformation can significantly improve the innovation efficiency of enterprises. This conclusion is still valid after stability tests such as replacement variables, delayed explanatory variables, replacement time windows,

high-dimensional fixed effects and Tobit models; The mechanism test shows that the alleviation of financing constraints and the improvement of total factor productivity are two important transmission paths; Heterogeneity analysis shows that the innovation efficiency improvement effect of digital transformation is more prominent in state-owned enterprises, large-scale enterprises, mature enterprises and highly competitive industries. This article provides the following management inspiration on how to improve the efficiency of enterprise innovation through digital transformation:

First, when promoting digital transformation, enterprises should pay attention to improving innovation efficiency, rather than expanding the quantity of output, and focus on promoting the deep integration of digital technology with research and development, production and management processes.

Second, enterprises should use digital infrastructure to improve information transparency and internal control to relieve financing constraints, take the initiative to connect with the digital credit evaluation system of the external capital market, and reduce the external financing cost and information asymmetry premium of long-term innovation projects.

Third, different enterprises should adopt differentiated strategies to seek innovative development in digital transformation. State-owned enterprises can take the lead in promoting the integration of digital systems with organizational and policy advantages. Large enterprises and mature enterprises should focus on the collaborative reinvention of digital resources and existing capabilities, while small and medium-sized enterprises, young enterprises and enterprises in low-competition industries need to give priority to supplementing basic digital capabilities, and share digital infrastructure with the help of external policies or industry alliances to avoid waste of resources caused by blindly following the trend.

References

- [1] Huang, Q., Yu, Y., & Zhang, S. (2019). Internet development and productivity improvement in manufacturing: Internal mechanisms and evidence from China. *China Industrial Economics*, 8, 5–23. <https://doi.org/10.19581/j.cnki.ciejournal.2019.08.001>
- [2] Xiao, X., & Qi, Y. (2019). Value dimensions and theoretical logic of industrial digital transformation. *Reform*, 8, 61–70.
- [3] Qi, H., Cao, X., & Liu, Y. (2020). The impact of the digital economy on corporate governance: Perspectives of information asymmetry and managerial irrational behavior. *Reform*, 4, 50–64.
- [4] Yu, B., & Yang, G. (2024). The impact of corporate digital transformation on innovation efficiency. *Journal of Southwest Minzu University (Humanities and Social Sciences Edition)*, 45(3), 80–92.
- [5] Feng, G., & Wen, J. (2008). An empirical analysis of the relationship between corporate governance and technological innovation in Chinese listed companies. *China Industrial Economics*, 7, 91–101. <https://doi.org/10.19581/j.cnki.ciejournal.2008.07.009>
- [6] Lu, X., & Lian, Y. (2012). Estimation of total factor productivity of Chinese industrial enterprises: 1999–2007. *China Economic Quarterly*, 11(2), 541–558. <https://doi.org/10.13821/j.cnki.ceq.2012.02.013>
- [7] Ju, X., Lu, D., & Yu, Y. (2013). Financing constraints, working capital management, and the sustainability of corporate innovation. *Economic Research Journal*, 48(1), 4–16.
- [8] Wu, F., Hu, H., Lin, H., & Ren, X. (2021). Corporate digital transformation and capital market performance: Evidence from stock liquidity. *Management World*, 37(7), 130–144, 10. <https://doi.org/10.19744/j.cnki.11-1235/f.2021.0097>

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.

Open Access

This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

