

A Study on the Impact of Digital Transformation on the Innovation Transformation Efficiency of Specialized and Sophisticated SMEs and Its Internal Mechanisms

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Abstract: Digital transformation, as a crucial engine for high-quality economic growth, is increasingly drawing attention to its impact on corporate innovation activities. Specialized and sophisticated SMEs, as a vital component of the national innovation system, are actively integrating into the digital wave, with digital transformation being key to enhancing their competitiveness. However, these enterprises also face unique resource challenges in the process of digital transformation, and whether their digital investment can effectively promote the transformation of innovative achievements into corporate profits is worth exploring in depth. Using Chinese A-share market specialized and sophisticated SMEs from 2018 to 2022 as the research subject, this paper empirically examines the impact of digital transformation on innovation transformation efficiency. The study reveals that digital transformation has a significant inhibitory effect on innovation transformation efficiency. Financing constraints play an intermediary role in this relationship. Cash holding level, proportion of technical department employees, and R&D investment intensity can all significantly weaken the negative impact of digital transformation.

Keywords: Digital Transformation; Innovation Transformation Efficiency; Specialized and Sophisticated SMEs.

1. Introduction

Digital transformation has become a crucial engine for high-quality economic growth in the modern economy. As enterprises actively integrate into the digital wave, the impact of digital transformation on corporate innovation activities is increasingly drawing attention from academia and industry practitioners. Specialized and sophisticated SMEs, as a vital component of the national innovation system, play an irreplaceable role in promoting technological progress and industrial upgrading. These enterprises are characterized by their focus on niche markets, mastery of core technologies, and strong innovation capabilities, making them important drivers of economic transformation and development.

However, specialized and sophisticated SMEs also face unique resource challenges in the process of digital transformation. Unlike large enterprises with abundant capital reserves and diversified financing channels, SMEs often operate under tight budget constraints and limited access to external financing. This raises an important question: whether their digital investment can effectively promote the transformation of innovative achievements into corporate profits remains uncertain and worth exploring in depth.

Current research on digital transformation mostly emphasizes its positive impact on enterprise performance and innovation output, while there is a lack of sufficient discussion on the unexpected consequences that digital transformation may trigger under resource constraints. Specifically, the process of digital transformation requires substantial upfront investment in hardware, software, and human capital, which may exacerbate financing constraints for SMEs and ultimately hinder their ability to convert innovation inputs into economic returns.

This paper focuses on specialized and sophisticated SMEs listed on the Chinese A-share market from 2018 to 2022. The research objectives are threefold: first, to examine the direct impact of digital transformation on innovation transformation

efficiency; second, to explore the internal transmission mechanisms, particularly the role of financing constraints; third, to identify boundary conditions that may moderate this relationship.

2. Literature Review and Hypothesis Development

2.1. Research on Specialized and Sophisticated SMEs

SMEs play a crucial role in economic and social development, serving as the foundation for maintaining economic growth, improving people's livelihood, ensuring employment, preventing risks, and promoting reform [1]. The concept of "specialized and sophisticated" encompasses four dimensions: specialization, refinement, differentiation, and innovation [2]. This strategy aims to guide enterprises to deepen professional capabilities, optimize management processes, clarify market positioning, and continuously pursue innovative development. In July 2011, the Ministry of Industry and Information Technology first introduced the concept in the "China Industrial Development and Industrial Policy Report (2011)", which gradually established it as a key orientation for SME growth and a focal point for policy support.

Since 2019, against the backdrop of global economic imbalances and escalating deglobalization trends, coupled with the continuous escalation of Sino-US trade friction, solving the "bottleneck" problem of core technologies has become particularly urgent. In this context, cultivating and developing specialized and sophisticated SMEs has become a key strategy for achieving technological breakthroughs and industrial upgrading [3]. In June 2021, the Ministry of Industry and Information Technology and five other departments jointly issued the "Guiding Opinions on Accelerating the Cultivation and Development of High-Quality Manufacturing Enterprises", aiming to promote the

rapid development of specialized and sophisticated "little giant" enterprises.

Although China has implemented a series of policies to promote the stable growth of specialized and sophisticated SMEs, they still face challenges in practice. These include lack of innovation incentives due to imperfect innovation mechanisms and systems, financing difficulties resulting in significant financing constraints [4], and "digital divide" and resource constraints encountered in the digital transformation process [5].

2.2. Economic Consequences of Digital Transformation

From a macro perspective, digital transformation can effectively promote the construction of diversified industrial technology innovation platforms and cultivate internationally competitive digital industrial clusters through the synergistic effects of industrial digitalization and digital industrialization, thereby significantly improving total factor productivity [6]. Digital transformation has alleviated the problem of information asymmetry, enabling large amounts of non-standardized and unstructured data to be transformed into valuable information for enterprise production and operation decisions [7]. Digital transformation has also had a positive impact on rural entrepreneurship activities, promoting equal distribution of entrepreneurial opportunities and significantly increasing rural household income levels [8].

From a micro perspective, digital transformation plays an important role in innovating the enterprise innovation environment. It can not only expand the freedom of innovation factor flow but also help optimize the organization and management of innovation activities, thereby significantly promoting the innovation performance of real enterprises [9]. Digital transformation is a key strategy for enterprises to improve performance and enhance economic value [10]. From the perspective of principal-agent theory, digital transformation can significantly improve the principal's ability to identify and control production risks, and strengthen internal information flow [11]. However, some scholars have reached different conclusions. Liu et al. [12] pointed out that due to scale and resource constraints, SMEs' investment in digital transformation may not directly lead to linear growth in output returns. Acemoglu and Restrepo [13] found that if the informatization process exceeds a reasonable range, it may lead to resource waste and labor misallocation, indirectly inhibiting the growth of total factor productivity.

2.3. Innovation Efficiency of Specialized and Sophisticated SMEs

Regarding internal factors affecting innovation efficiency. First, innovation efficiency is related to enterprise scale. According to Schumpeter's innovation hypothesis, enterprise scale has an important impact on innovation level. Specialized and sophisticated SMEs show stronger innovation motivation than large enterprises [14], but due to scale limitations, these enterprises often face capital shortages and lack stable business plans, increasing operational risks [15]. Second, management innovation affects innovation performance. Management innovation positively affects the breadth of external knowledge search and weakens organizational inertia, thereby promoting innovation performance [16]. Third, financing constraints affect innovation efficiency. Due to information asymmetry and high R&D costs, financing difficulties prevent effective

knowledge resource diffusion and sharing [17].

Regarding external factors. First, government subsidies and tax incentives are important external factors. Government subsidies can alleviate losses from innovation imitation and support innovation behavior [18]. Second, industry-university integration is another key factor. Cooperation between enterprises and universities promotes innovation quantity and quality [19]. Third, regional high-quality development also affects innovation efficiency. Innovation, coordination, and open development significantly promote innovation performance, while green and shared development may constrain innovation motivation [20].

2.4. Hypothesis Development

Based on resource-based theory, information asymmetry theory, and organizational inertia theory, this study proposes that the impact of digital transformation on innovation transformation efficiency can be understood through three logical chains. First, resource-based theory reveals the finiteness of enterprise resources, and digital investment may occupy core resources that should be applied to innovation transformation, thereby directly inhibiting innovation transformation efficiency (H1). Second, information asymmetry theory indicates that the high investment and long cycle characteristics of digital transformation may exacerbate information gaps between enterprises and external investors, increase financing costs, and indirectly hinder the market transformation of innovation achievements through increased financing constraints (H2). Third, resource-based theory and organizational inertia theory suggest that enterprise resource base and internal conditions significantly affect the strength of the above relationship.

H1: Digital transformation negatively affects innovation transformation efficiency of specialized and sophisticated SMEs.

H2: Financing constraints mediate the relationship between digital transformation and innovation transformation efficiency.

H3: Cash holding level negatively moderates the relationship between digital transformation and innovation transformation efficiency.

H4: Proportion of technical department employees negatively moderates the relationship between digital transformation and innovation transformation efficiency.

H5: R&D investment intensity negatively moderates the relationship between digital transformation and innovation transformation efficiency.

3. Research Design

3.1. Sample and Data

This study selects specialized and sophisticated SMEs listed on the Chinese A-share market from 2018 to 2022 as research subjects. The sample excludes ST and *ST companies, financial enterprises, companies with missing key data, and companies listed for less than one year. After screening, 134 eligible enterprises are included, totaling 670 observations. Digital transformation data is obtained through Python text mining and keyword frequency analysis, while other variables are sourced from the CSMAR database.

3.2. Variable Measurement

3.2.1. Dependent Variable: Innovation Transformation Efficiency (Innov)

Following Tan et al. [21], this study uses the DEA-BCC model to measure innovation transformation efficiency. Input variables include total patent applications and sales expenses, while output variable is total operating revenue.

3.2.2. Independent Variable: Digital Transformation (Digital)

Following Wu et al. [7], this study adopts the text analysis method to measure digital transformation. Using Python web scraping technology, we batch collect annual reports of listed companies from 2018 to 2022 and extract keywords from five dimensions: artificial intelligence, blockchain, cloud computing, big data, and digital technology application scenarios. The total word frequency of digital transformation-related terms is standardized by total word count of the annual report and then logarithmized to construct the digital transformation indicator.

3.2.3. Mediating Variable: Financing Constraints (SA)

Following Li et al. [22] and Wang et al. [23], this study uses the SA index to measure financing constraints. The formula is as follows:

$$SA = -0.737 \times \text{Size} + 0.043 \times \text{Size}^2 - 0.04 \times \text{Age}$$

Where Size denotes the natural logarithm of total assets, and Age denotes the number of years since establishment. The calculated SA index may yield negative values. To facilitate intuitive comparison of financing constraints across enterprises, the absolute value of the SA index is adopted. A larger SA index indicates more severe financing constraints faced by the enterprise.

3.2.4. Moderating Variables

Cash holding level (Cash) is measured as the natural

logarithm of enterprise cash scale. Technical department employee proportion (TechStaff) is calculated as technical department employees divided by total employees. R&D investment intensity (RDSpendSumRatio) is R&D expenditure divided by operating revenue.

3.2.5. Control Variables

Following Pan et al. [24] and Shi et al. [25], control variables include accounts receivable ratio (REC), inventory ratio (INV), ROA, ROE, board size (Boardsize), growth rate (Growth), independent director ratio (IndDirectorRatio), duality (Dual), shareholding ratio of largest shareholder (Shrcr1), Tobin's Q, management expense ratio, (Mfee) and SOE indicator (SOE).

3.3. Empirical Model

This study establishes a two-way fixed effects model:

$$Innov_{i,t} = \alpha + \alpha_0 Digital_{i,t} + \sum \alpha_j Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

4. Empirical Results

4.1. Descriptive Statistics

Table 1 presents descriptive statistics. The mean of innovation transformation efficiency is 0.845, with standard deviation of 0.049, indicating that sample enterprises achieve 84.5% efficiency on average in converting innovation inputs to outputs, though substantial variation exists near the efficiency frontier. The minimum value is 0.745 and maximum is 1.000, suggesting room for improvement among most enterprises. The mean of digital transformation is 30.719, but the standard deviation is as high as 59.369, with median of only 8, indicating highly right-skewed distribution where few enterprises have advanced digital transformation while most remain at early stages.

Table 1. Descriptive Statistics

Variable	N	Mean	SD	Median	Min	Max
Innov	670	0.845	0.049	0.838	0.745	1
Digital	670	30.719	59.369	8	0	366
SA	670	3.871	0.183	3.882	3.305	4.425
Cash	670	19.784	0.933	19.771	16.402	22.761
TechStaff	670	30.314	19.272	23.9	0.84	85.04
RDSpendSumRatio	670	7.876	5.642	6.185	0.25	36.38
REC	670	0.176	0.089	0.167	0.001	0.446
INV	669	0.136	0.074	0.125	0	0.434
ROA	670	0.045	0.073	0.048	-0.414	0.323
ROE	670	0.061	0.136	0.076	-1.32	0.528
Boardsize	670	7.937	1.395	8	4	13
Growth	667	0.171	0.392	0.123	-0.633	4.456
IndDirectorRatio	670	38.349	5.432	37.5	14.29	57.14
Dual	670	0.448	0.498	0	0	1
Shrcr1	670	29.187	13.682	28.37	6.93	80.992
TobinQ	670	2.347	1.994	1.854	0.857	22.557
Mfee	670	0.077	0.040	0.07	-0.111	0.292
SOE	670	0.119	0.325	0	0	1

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.2. Baseline Regression

Table 2 reports baseline regression results. Regardless of

whether control variables are included, and whether individual fixed effects or two-way fixed effects models are used, the coefficient of digital transformation is significantly negative at the 5% or 1% level. In the two-way fixed effects

model controlling for enterprise characteristics and individual and time heterogeneity, for every unit increase in digital transformation, enterprise innovation transformation efficiency decreases by approximately 0.00020 units.

Table 2. Baseline Regression Results

Variable	(1) Individual FE	(2) Two-way FE	(3) Individual FE + Controls	(4) Two-way FE + Controls
Digital	-0.00015**	-0.00020***	-0.00017**	-0.00020**
	(-2.21)	(-2.79)	(-2.16)	(-2.37)
Controls	No	No	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
Observations	670	670	666	666

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.3. Robustness Checks

This study conducts several robustness checks following Yuan et al. [26], Tian et al. [27], and Liu et al. [28]. First, excluding enterprises with zero digital transformation, the

coefficient remains significantly negative (-0.00019**). Second, excluding the year 2020, the coefficient is -0.00020**. Third, retaining only manufacturing samples, the coefficient is -0.00016**. Fourth, excluding enterprises with duration less than 10 years, the coefficient is -0.00019**. All results confirm the robustness of the core conclusion.

Table 3. Robustness Checks

Variable	(1) Excluding Zero Digital	(2) Excluding 2020	(3) Manufacturing Only	(4) Excluding Age<10
Digital	-0.00019**	-0.00020**	-0.00016**	-0.00019**
	(-2.37)	(-2.09)	(-2.52)	(-2.34)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	556	532	557	656

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.4. Endogeneity Treatment

To address potential endogeneity, this study employs two instrumental variable strategies. Following Yang et al. [29] and Dong et al. [30], the nonlinear instrumental variable is constructed as the cubic deviation of enterprise digital transformation from the provincial mean, capturing heterogeneous responses to regional digital trends while satisfying the exclusion restriction. Following Gong et al. [31] and Yang et al. [32], the lagged one-period digital transformation serves as an alternative instrument, exploiting the path dependence of technology adoption.

Table 4 reports the two-stage least squares results. Both instruments pass diagnostic tests: the Kleibergen-Paap rk LM statistics reject under identification, and the Cragg-Donald Wald F statistics (570.092 and 68.317) exceed the Stock-Yogo critical value, confirming instrument validity. In the second stage, the coefficient of Digital remains significantly negative in both specifications (-0.0002* and -0.0004*), consistent with baseline regression. This confirms that endogeneity does not drive the core conclusion.

Table 4. Endogeneity Treatment

Variable	(1) IV: Nonlinear	(2) IV: Lagged One-period
First Stage		
Instrument	0.0000102***	0.3472***
	(0.0000)	(0.0889)
F-statistic	570.092	68.317
Second Stage		
Digital	-0.0002*	-0.0004*
	(0.0001)	(0.0002)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	666	535
Kleibergen-Paap rk LM	12.940***	8.610***

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.5. Mediation Effect Test

Following Jiang [33], this study uses the two-step method to test mediation effects. Table 5 shows that digital transformation significantly increases financing constraints (coefficient = 0.00014***). Combined with existing research showing that financing constraints inhibit innovation efficiency, it can be inferred that financing constraints serve as a transmission path.

Table 5. Mediation Effect Test

Variable	SA
Digital	0.00014***
	(2.69)
Controls	Yes
Firm FE	Yes
Year FE	Yes
Observations	666
R-squared	0.938

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.6. Moderating Effect Test

Table 6 reports grouping regression results by median of moderating variables. In high cash holding, high technical staff ratio, and high R&D investment groups, the coefficients of digital transformation are insignificant; while in low groups, coefficients are significantly negative. This indicates that these factors effectively mitigate the negative impact of digital transformation.

Table 6. Moderating Effect Test

Variable	(1) High Cash	(2) Low Cash	(3) High Tech	(4) Low Tech	(5) High R&D	(6) Low R&D
Digital	-0.00004	-0.00042***	-0.00013	-0.00073***	-0.00004	-0.00022**
	(-0.54)	(-5.03)	(-1.52)	(-2.84)	(-0.73)	(-2.07)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	333	333	334	332	334	332

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.7. Heterogeneity Analysis

Table 7 reports regional heterogeneity results. The coefficient of Digital in the eastern region is -0.0003, significant at the 1% level, while coefficients in western and central regions are statistically insignificant. This indicates that the negative impact of digital transformation on innovation transformation efficiency mainly concentrates in the eastern region.

The regional divergence stems from two factors. First, eastern enterprises initiated digital transformation earlier with higher investment intensity, facing more intense market competition and faster technology iteration, which amplifies resource crowding-out effects during transformation. Their innovation activities are more susceptible to disruption from massive resource reallocation. Second, eastern enterprises operate closer to the efficiency frontier where marginal improvement is harder, making organizational friction and adaptation costs more pronounced. In contrast, central and western enterprises remain at early transformation stages with lower digital penetration, where resource competition between transformation and innovation is less severe, and the inhibitory effect has not yet manifested statistically.

Table 7. Regional Heterogeneity

Variable	(1) Western	(2) Eastern	(3) Central
Digital	0.0002	-0.0003***	-0.00001
	(0.67)	(-3.00)	(-0.09)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	25	586	55

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5. Conclusions and Implications

5.1. Conclusions

This study investigates the impact of digital transformation on innovation transformation efficiency of specialized and sophisticated SMEs listed on China's A-share market from 2018 to 2022. The main findings are as follows.

First, digital transformation significantly inhibits innovation transformation efficiency. This negative effect remains robust after a series of tests, including excluding zero-digital firms, removing the pandemic year, retaining only manufacturing firms, and dropping young firms. Second, financing constraints play a mediating role: digital transformation aggravates financing constraints, which in turn suppresses innovation conversion. Third, cash holding level, proportion of technical staff, and R&D investment intensity negatively moderate the main effect. In high-level groups of these moderators, the negative impact of digital transformation becomes insignificant, while in low-level groups it remains significantly negative. Fourth, regional heterogeneity shows that the inhibitory effect exists mainly in the eastern region, with no clear evidence in central and western regions.

5.2. Policy Implications

Governments should adopt differentiated guidance strategies: for eastern regions, encourage quality over quantity in digital investment; for central and western regions, focus on building basic innovation capacity before rushing into digitalization. Financial support mechanisms should be established to alleviate financing constraints during transformation, such as special loan subsidies and intellectual property pledge financing. Tax incentives and R&D super-deductions can help firms maintain healthy cash buffers and sustained R&D efforts.

5.3. Firm-level Implications

Enterprises should optimize financial structure and maintain adequate cash reserves to cushion resource crowding-out. Strengthening technical talent reserves enhances digital absorption capacity and reduces

organizational friction. Stable R&D investment should be sustained rather than cut during digital transformation. Firms must carefully assess transformation pace to avoid over-commitment and ensure dynamic balance between digital investment and innovation efficiency.

5.4. Innovations

First, contrary to the prevailing positive-effect paradigm, this study reveals an inhibitory effect of digital transformation on innovation transformation efficiency, offering a new perspective. Second, it systematically examines the mediating role of financing constraints and the moderating roles of cash holdings, technical talent, and R&D intensity. Third, by focusing on specialized and sophisticated SMEs, it extends digital transformation theory to this specific understudied group.

5.5. Limitations

The sample covers only listed firms from 2018–2022, limiting generalization to non-listed SMEs and long-term dynamic analysis. The text-based digital transformation measure captures strategic disclosure but may not reflect actual implementation depth or quality. Future research should extend the time window, incorporate multi-dimensional digital measures, and explore other mediating pathways and boundary conditions.

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