



Digital transformation and SME innovation: The mediating role of financing constraints

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ABSTRACT

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This study explores the impact of digital transformation on the innovation of small and medium-sized enterprises (SMEs). Based on 2018–2024 firm-level datasets, our results verify that digital transformation delivers remarkable promotional effects on SME innovation, improving innovation across both quantity and quality dimensions. From an economic perspective, a one-standard-deviation increase in digital transformation brings a 3.5% gain in innovation quantity and a 5.7% lift in innovation quality. Specifically, digital transformation fosters more patent applications and grants, and also increases the technological value of patents. Financing constraints are found to partially mediate the relationship under investigation. Digital transformation can alleviate information asymmetry, enhance the credibility of enterprises, and thus alleviate financing constraints and promote more continuous innovation activities. Further heterogeneity analysis shows that the positive effect of digital transformation on innovation is significantly stronger for non-state-owned enterprises (non-SOEs) than for state-owned enterprises (SOEs) in terms of ownership. This could be because non-SOEs are more market-sensitive and have stronger incentives to transform. As for regional heterogeneity, digital transformation has a significant effect on promoting innovation in the eastern region, and also exerts a positive effect in the west, with a stronger marginal impact. This study builds theoretical bases and implementable guidance for enterprises, regulators, and financial lenders, helping SMEs overcome innovation challenges and encouraging the digital and real economies to become more deeply intertwined.

Contribution/Originality: This study contributes to the existing literature by examining how digital transformation affects the quantity and quality of SME innovation. It further identifies financing constraints as a mediating channel, using firm-level evidence from NEEQ-listed enterprises.

1. INTRODUCTION

SMEs are a key engine of national economic growth and a primary source of technological innovation. Strengthening the principal position of enterprises in technological innovation is crucial for deepening the integration of technological and industrial innovation. Amid the ongoing fusion between digital transformation and tangible industrial sectors, digital transformation has become an imperative for SMEs to overcome resource constraints (Guo, Liu, & Yu, 2025) and cultivate innovation momentum (Saeedikiya, Salunke, & Kowalkiewicz, 2025).

Prior literature has examined the linkage between digital transformation and innovation, but scholars have not reached unified conclusions. Some scholars suggest that digital transformation can promote innovation (Gaglio, Kraemer-Mbula, & Lorenz, 2022; Shao, Xu, & Shan, 2024; Yang, Nie, Li, & Wang, 2023; Zhao, Chen, Yuan, Yu, & Zhang, 2024); while others find an inverted U-shaped relationship, arguing that excessive digital transformation may inhibit innovation (Dian, Song, & Li, 2024; Liu, 2025; Liu & Wang, 2025); a third group reports an insignificant effect

of digital technology application on enterprise innovation (Usai et al., 2021). In terms of the mechanism of digitalization to promote innovation in SMEs, previous studies have found mediating mechanisms such as equity incentives and managerial myopia (Gu & He, 2026), global innovation networks (Li, Dang, & Zhao, 2022; Tian, Lai, Dong, & Xu, 2025), knowledge flows, and R&D investment (Chen & Kim, 2023). It also emphasizes that by promoting the transformation of knowledge structure and resource flow, digital technologies can better position SMEs to innovate independently (Zheng et al., 2025).

Most existing mechanism analyses focus on factor flow (Cui & Liu, 2025), while few studies examine this relationship from the credit financing perspective. Stable capital provision lays the foundation for firms' innovation activities. Berg, Burg, Gombović, and Puri (2020) claim that digital footprints are useful in predicting borrower default and are a valid complement to traditional credit information, thus mitigating information frictions between lenders and improving credit accessibility. Galilea, Farazi, and Mare (2026) point out that digital payment records generated during business operations convey credible information on firms' revenue and cash flows to financial institutions, enabling banks to assess corporate creditworthiness, bridge bank-firm information asymmetry, expand credit supply, and ease firms' financial constraints. Alleviated financing pressure enables firms to continuously scale up R&D investment and generate more innovative outputs. It follows that optimized credit financing represents a vital channel through which digital transformation empowers corporate innovation, with financial constraints functioning as a core mediator connecting digital transformation and innovation.

Meanwhile, most current research focuses on large enterprises. In contrast to larger, resource-rich enterprises, SMEs can vary significantly in their financing capacity, digital transformation, and innovation. Ignoring this group undermines the theoretical soundness and practical utility of current frameworks for SMEs. Hence, this study raises two questions: Can digital transformation enhance innovation in SMEs, and if so, is this effect mediated by the relaxation of financing constraints?

Our study makes several contributions. Departing from prior studies on large firms, we focus on SMEs. This change expands the research horizon of digital transformation, provides more group-specific results, and sheds new insight on innovation across firm sizes. Meanwhile, this study discusses enterprise innovation in two aspects: quantity and quality. To measure innovation quality, we construct an index by assigning different weights to various types of patents. This approach preserves the quality-gradient information of patent types while avoiding the problem of sparsity in patent citation data commonly observed among SMEs. Finally, at the mechanism level, this paper validates the transmission path in which financing constraints serve as a mediator in the SME context. Different from existing studies based on large enterprises, SMEs display marked disparities in financing constraints and information transparency. This study provides new support for understanding how digitalization drives innovation in SMEs. Furthermore, our findings provide financial institutions with a practical reference for assessing SMEs' innovation potential based on their digital progress and designing differentiated credit schemes to alleviate financing constraints.

2. THEORETICAL ANALYSIS AND HYPOTHESIS DEVELOPMENT

Digital transformation represents an integrated process that allows enterprises to deploy digital tools for restructuring production models, refining service mechanisms, and boosting value-generating capabilities. Furthermore, it broadens enterprises' internal and external information channels and effectively alleviates information asymmetry. Supported by digital facilities covering IoT hardware and industrial Internet platforms, enterprises can capture technological frontiers and market dynamics in real time (Ghosh, Hughes, Hodgkinson, & Hughes, 2022). Such advantages help enterprises detect untapped business needs and creative development directions far more precisely, ultimately fostering more innovation activities.

Digital transformation can accelerate patenting from R&D and shorten the turnaround time for patent approval (Qiao, Li, & Hu, 2025); on the other hand, it stimulates high-frequency innovation by reducing innovation costs and risks. For example, digital simulation and emulation technologies can reduce the repeated testing expenditures in

research initiatives and improve R&D productivity (Acemoglu & Restrepo, 2018); blockchain and similar technologies improve trust and coordination in cross-organizational collaborations, facilitating the generation of joint innovation outcomes. Moreover, data-driven refined management helps filter out unnecessary information noise, allowing R&D investment to focus on high-potential areas, thereby optimizing resource allocation and enhancing the efficiency of innovation. Digital technologies enable full lifecycle data tracking and supervision of innovation, allowing enterprises to conduct in-depth analysis of R&D, production, and sales processes, thereby optimizing quality control. Importantly, digital intellectual property management tools can systematically track inventions from creation to application, ensuring effective protection of innovative outputs (Holgersson & Aaboen, 2019) and, in turn, enhancing their technological content and market value. Accordingly, this study puts forward the research hypotheses listed below.

H₁: Digital transformation promotes innovation in SMEs.

H_{1a}: Digital transformation increases the quantity of innovation in SMEs.

H_{1b}: Digital transformation improves the quality of innovation in SMEs.

For SMEs that primarily rely on debt financing as their external funding source, their financing constraints often stem from issues such as information asymmetry, insufficient collateral, and high cash flow fluctuations. Digital transformation can relieve these financing constraints (Wei & Li, 2024), thus enabling enterprises to better access capital. An (2026) reveals that the digital transformation of SMEs generates traceable multidimensional data regarding operations, real-time business, customer insights, and supply chain documentation. This alleviates information asymmetry and inter-organizational information barriers between banks and enterprises, thus effectively reducing firms' debt financing costs. Active participation in digital transformation can improve the transparency and credibility of SMEs. This makes them preferred candidates for resource distribution, enabling them to obtain external financing at lower costs. Meanwhile, it improves their capability to access government subsidies, policy support, and other preferential resources. This improves their liquidity and widens their access to external finance sources. Innovation activities are costly and time-consuming, requiring access to stable external financing. The reduction of financing constraints produces a stable capital environment and enables enterprises to take on risk. This ensures a steady stream of capital injection into innovation that will improve the sustainability and quality of innovation outcomes.

H₂: Digital transformation can foster innovation in SMEs by alleviating financial constraints.

3. METHODOLOGY AND DATA

3.1. Models and Methodology

To quantify the influence of digital transformation on innovation, we adopt a baseline OLS model with the exact specification shown in Equation 1.

$$\text{Innov}_{i,t}(\text{Lndex}_{i,t}) = \beta_0 + \beta_1 \text{Digital}_{i,t} + \sum \beta_i Z_{i,t} + \text{Firm} + \text{Industry} + \text{Region} + \text{Year} + \epsilon_{i,t} \quad (1)$$

On this basis: i and t respectively represent different years and enterprises. Innovation quantity (*Innov*) and quality (*Lndex*) are dependent variables. *Digital* denotes the level of digital transformation, acting as an independent variable, while controlling for other variables that may influence corporate innovation. $Z_{i,t}$ is a vector of firm-level control variables and $\epsilon_{i,t}$ represents the error term. Firm, industry, regional, and year fixed effects are denoted by *Firm*, *Industry*, *Region*, and *Year*.

Moreover, to assess the mediating role of financing constraints, Equation 2 and Equation 3 are subsequently constructed.

$$FC_{i,t} = \delta_0 + \delta_1 \text{Digital}_{i,t} + \sum \delta_i Z_{i,t} + \text{Firm} + \text{Industry} + \text{Region} + \text{Year} + \epsilon_{i,t} \quad (2)$$

$$\text{Innov}_{i,t}(\text{Lndex}_{i,t}) = \eta_0 + \eta_1 \text{Digital}_{i,t} + \eta_2 FC_{i,t} + \sum \eta_i Z_{i,t} + \text{Firm} + \text{Industry} + \text{Region} + \text{Year} + \epsilon_{i,t} \quad (3)$$

Where, *FC* proxies for financing constraints. The coefficient δ_1 in Model (2) is the coefficient to be tested. If δ_1 is negative, it indicates that digital transformation can alleviate financing constraints. The coefficients η_1 and η_2

in Model (3) are the parameters to be tested. The results indicate that when η_1 is positive and η_2 is negative, the alleviation of financing constraints is an important mechanism for digital transformation to promote innovation and improve the competitiveness of SMEs.

3.2. Data

Using 2018–2024 data from Chinese NEEQ-listed firms, we removed ST/*ST companies, finance and insurance companies, and samples with missing financial information. The final sample consists of 27,076 observations after the screening procedures. Financial and innovation data are obtained from CSMAR and the annual reports of listed firms, while digital transformation indicators were constructed using Python-based keyword analysis of annual reports.

Dependent variable: Enterprise innovation (*Innov* / *Lindex*). Following Xu, Ji, Qiao, and Huang (2025), we measure enterprise innovation in quantity and quality. Innovation quantity (*Innov*) is defined as the natural log of (1 + a firm's total patent applications in a given year). Innovation quality (*Lindex*) is constructed by weighting invention, utility model, and design patents with scores of 5, 3, and 1, summing them, and taking the log of one plus the resulting sum (Shen, Zhao, & Wu, 2017).

Explanatory variable: Digital transformation (*Digital*). Following Wu, Hu, Lin, and Ren (2021), we constructed a digital transformation indicator system. Using web-crawling technology to extract text from listed firms' annual reports, we calculated keyword frequencies for each dimension and then aggregated them to construct an initial indicator. To mitigate right skewness in the data, we applied a log transformation after adding 1 to the initial indicator, ultimately deriving an indicator of corporate digital transformation maturity.

Mediating variable: Financing Constraints (FC). Based on Balan and Norden (2024), we construct the index (FC) using firm size and age. The severity of financing constraints is gauged by the absolute value of this index.

To control for other influences, we also control for a series of variables, including firm size, firm age, current ratio, cash holdings, and return on assets. Variable descriptions are provided in Table 1.

Table 1. Variable definitions.

Symbol	Definition
Innov	$\text{Ln}(\text{Total patent applications}+1)$
Lindex	$\text{Ln}(5\text{Inv}+3\text{Util}+1\text{Des}+1)$
Digital	$\text{Ln}(\text{Digital transformation word frequency}+1)$
FC	$ \text{SA} = -0.737 \times \text{Size} + 0.043 \times \text{Size}^2 - 0.04 \times \text{Age} $
Size	$\text{Ln}(\text{Total Assets})$
Age	Year of observation - Year of founding
Liquid	Current assets / Current liabilities
Cash	Cash and Cash Equivalents / Total Assets
Roa	Net income / Average total assets
Ocf	Cash flow from operating activities / Total assets
Dual	Dummy variable for CEO duality, coded 1 if the chairman also serves as the general manager (CEO), and 0 otherwise.

4. RESULTS

4.1. Descriptive Statistics

Descriptive statistics are reported in Table 2.

Table 2. Descriptive statistics.

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Innov	27076	1.139	1.078	0.000	6.118
Lindex	27076	1.824	1.600	0.000	7.589
Digital	27076	1.081	1.218	0.000	5.394
FC	27076	3.688	0.246	1.530	5.410
Size	27076	4.887	0.976	1.610	10.860
Age	27076	2.743	0.379	0.000	4.090
Liquid	27076	2.749	3.387	-3.510	25.390
Cash	27076	0.140	0.144	0.000	0.980
Roa	27076	0.021	0.136	-2.400	1.160
Ocf	27076	0.039	0.131	-2.896	1.384
Dual	27076	0.504	0.500	0.000	1.000

With a standard deviation (SD) of 1.218 and a maximum of 5.394, it exhibits wide dispersion across enterprises. The mean is 1.139, and the SD is 1.078. It shows that the distribution of innovation levels of the sample enterprises is relatively concentrated. The minimum is 0, and the maximum is 7.589, which means that a few highly innovative enterprises are pulling up the overall mean. has a mean of 1.824 and an SD of 1.600, with a range of 0 to 7.589. The distribution is more dispersed, which means that the enterprises are more heterogeneous under this index. As for the control variables, we list the factors affecting enterprise innovation from the perspectives of enterprise size, enterprise age, cash holdings, etc.

4.2. Benchmark Regression

Table 3 reports the estimates of digital transformation on innovation in SMEs.

Table 3. Benchmark regression.

Dependent Variables	Innov		Lindex	
	(1)	(2)	(3)	(4)
Digital	0.037*** (0.011)	0.029*** (0.011)	0.061*** (0.016)	0.047*** (0.016)
Size		0.160*** (0.021)		0.261*** (0.031)
Age		0.005 (0.095)		0.020 (0.142)
Liquid		-0.000 (0.000)		-0.000 (0.000)
Cash		0.064 (0.069)		0.111 (0.104)
Roa		0.209*** (0.057)		0.340*** (0.085)
Ocf		-0.143*** (0.052)		-0.233*** (0.078)
Dual		0.003 (0.011)		0.010 (0.017)
Constant	1.053*** (0.018)	0.264 (0.404)	1.773*** (0.027)	0.452 (0.606)
Firm/ Year	Yes	Yes	Yes	Yes
Region/ Industry	No	Yes	No	Yes
N	27076	27076	27076	27076
R ²	0.004	0.008	0.002	0.007

Note: Standard errors are reported in parentheses. ***, denote statistical significance at the 1% levels, respectively.

Column (1) shows that it is significant, with a coefficient of 0.037. This indicates that digital transformation increases the quantity. Column (2) adds firm-level controls and industry/region fixed effects, which reduce the coefficient from 0.037 to 0.029, though it remains significant. H1a is confirmed. Columns (3) and (4) show that digital transformation significantly improves innovation quality, with coefficients of 0.061 and 0.047 (both at the 1% level). This positive relationship supports H1b.

From an economic interpretation perspective, a one-standard-deviation increase in digital transformation (SD=1.218) raises innovation quantity by approximately 3.5% and improves innovation quality by roughly 5.7%. The results verify that digital transformation can consistently empower the innovation development of SMEs. Meanwhile, they also reveal that upgrading innovation capacity relies heavily on the long-term accumulation of digital construction; minor short-term improvements in the level of digital transformation alone cannot generate breakthrough growth in innovation in the short run.

This evidence confirms the positive effect of digital transformation on innovation in SMEs, supporting H1.

4.3. Endogeneity Test

The relationship between digital transformation and innovation could be bidirectional. On the one hand, digital transformation helps innovation activities. On the other hand, enterprises that are already more innovative may attract more investment, which then encourages further digital transformation.

Table 4. Endogeneity test.

Dependent Variables	Innov	Index
	(1)	(2)
Digital	0.099** (0.050)	0.122* (0.074)
Constant	YES	YES
Firm/ Year/ Region/ Industry	YES	YES
N	19660	19660
R ²	0.006	0.006
Cragg-Donald Wald F	1170.747	1170.747
Kleibergen-Paap rk Wald F statistic	450.840	450.840
Kleibergen-Paap rk LM statistic	379.091	379.091
P-val	0.000	0.000

Note: Standard errors are reported in parentheses. **, and * denote statistical significance at the 5%, and 10% levels, respectively.

To mitigate endogeneity, we apply a two-stage least squares (2SLS) instrumental variable estimation. This study exploits the heteroskedastic structure of the model and generates valid instruments through demeaning and cubic transformations to satisfy relevance and exogeneity requirements (Hailemariam & Erdiaw-Kwasie, 2023). This study employs the cube of the difference between an enterprise's digital transformation index and the mean digital transformation index of its industry within the same province and year as an instrumental variable for endogeneity testing. Table 4 shows that there are no weak instrumental variables, and the empirical results exhibit a certain degree of robustness.

4.4. Robustness Test

Table 5 reports the outcomes of robustness exercises designed to validate the main regression.

Table 5. Robustness tests.

Dependent Variables	(1)		(2)	(3)	
	Innov	Lndex	Patent	Innov	Lndex
Digital	0.031*** (0.012)	0.049*** (0.018)	0.030*** (0.008)	0.036*** (0.013)	0.055*** (0.019)
Size	0.169*** (0.022)	0.276*** (0.033)	0.160*** (0.016)	0.162*** (0.025)	0.260*** (0.037)
Age	0.014 (0.096)	0.029 (0.145)	0.043 (0.074)	-0.175 (0.113)	-0.221 (0.168)
Liquid	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Cash	0.054 (0.076)	0.081 (0.114)	0.053 (0.054)	0.016 (0.086)	0.030 (0.127)
Roa	0.252*** (0.063)	0.406*** (0.095)	0.164*** (0.044)	0.219*** (0.072)	0.363*** (0.107)
Ocf	-0.167*** (0.058)	-0.287*** (0.087)	-0.133*** (0.040)	-0.136*** (0.065)	-0.227*** (0.097)
Dual	0.003 (0.012)	0.009 (0.019)	0.001 (0.009)	0.011 (0.013)	0.022 (0.019)
Constant	0.259 (0.427)	0.437 (0.644)	-0.211 (0.314)	1.010** (0.511)	1.556** (0.759)
Firm/ Year/ Region/ Industry	Yes	Yes	Yes	Yes	Yes
N	23249	23249	27076	20804	20804
R ²	0.009	0.009	0.011	0.010	0.009

Note: Standard errors are reported in parentheses. ***, ** denote statistical significance at the 1%, 5% levels, respectively.

We perform robustness tests: (1) excluding samples from the special year 2020; (2) using invention patent applications as an alternative innovation metric; and (3) excluding samples from municipalities. These results remain consistent with the baseline findings.

4.5. Mechanism Verification

While the preceding analysis confirms that digital transformation can promote innovation, the exact transmission channel remains unexplored.

Table 6. Mechanism testing.

Dependent Variables	Innov	FC	Innov	Lndex	FC	Lndex
	(1)	(2)	(3)	(4)	(5)	(6)
Digital	0.029*** (0.011)	-0.005*** (0.000)	0.026*** (0.011)	0.047*** (0.016)	-0.005*** (0.000)	0.043*** (0.016)
FC			-0.572*** (0.158)			-0.777*** (0.237)
Size	0.160*** (0.021)	-0.033*** (0.001)	0.141*** (0.021)	0.261*** (0.031)	-0.033*** (0.001)	0.236*** (0.032)
Age	0.005 (0.095)	-0.022*** (0.004)	-0.007 (0.095)	0.020 (0.142)	-0.022*** (0.004)	0.003 (0.142)
Liquid	-0.000 (0.000)	-0.000* (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000* (0.000)	-0.000 (0.000)
Cash	0.064 (0.069)	-0.021*** (0.003)	0.053 (0.069)	0.111 (0.104)	-0.021*** (0.003)	0.095 (0.104)
Roa	0.209*** (0.057)	0.017*** (0.002)	0.219*** (0.057)	0.340*** (0.085)	0.017*** (0.002)	0.353*** (0.085)
Ocf	-0.143*** (0.052)	0.021*** (0.002)	-0.131*** (0.052)	-0.233*** (0.078)	0.021*** (0.002)	-0.217*** (0.078)
Dual	0.003 (0.011)	-0.001 (0.000)	0.002 (0.011)	0.010 (0.017)	-0.001 (0.000)	0.009 (0.017)
Constant	0.264 (0.404)	4.025*** (0.018)	2.566*** (0.752)	0.452 (0.606)	4.025*** (0.018)	3.577*** (1.130)
Firm/ Year/ Region/ Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	27076	27076	27076	27076	27076	27076
R ²	0.008	0.800	0.009	0.007	0.800	0.008

Note: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Based on the analysis, we employ a stepwise approach to examine whether financing constraints serve as a valid mediator. In Table 6, column (1) shows that digital transformation has a positive effect on innovation quantity. Column (2) shows that digital transformation can reduce the financing constraints of enterprises. Furthermore, in column (3), with the mediator introduced, the coefficient decreases from 0.029 to 0.026, and the coefficient is negative at the 1% significance level. This result satisfies the judgment criteria for mediation effects, demonstrating that financing constraints serve as a partial mediator. Similarly, columns (4) to (6) confirm the same mediating path for innovation quality.

Thus, the hypothesis H2 is verified.

4.6. Heterogeneity Test

Moreover, this study investigates the heterogeneity of the effect of digital transformation on SME innovation by property rights and region. Results are shown in Tables 7 and 8.

Table 7 presents the results on heterogeneity of property rights. For non-state-owned enterprises (non-SOEs), the coefficients are significantly positive (0.031 and 0.050), while those for state-owned enterprises (SOEs) are insignificant. Compared with SOEs, non-SOEs are subject to stronger market competition and market-driven incentives, which make them more likely to embrace digital transformation to optimize resources and promote innovation.

The negative and insignificant coefficients for SOEs reflect two factors. At present, digital transformation is concentrated in high-value-added and high-tech sectors, while low-value-added or resource-dependent industries (e.g., agriculture, fisheries, and mining) are falling behind. SOEs are largely concentrated in such traditional industries. Moreover, the benefits of digital transformation for SOEs remain to be realized. Their transformation priorities are often more related to national strategies and long-term objectives, such as fundamental digital R&D and data governance, rather than short-term operational gains. Therefore, the impact on short-term performance is modest, and the transformation may even incur some additional costs at times.

Table 7. Test of property rights heterogeneity.

Dependent Variables	(1) SOEs		(2) non-SOEs	
	Innov	Lndex	Innov	Lndex
Digital	-0.016 (0.060)	-0.011 (0.087)	0.031*** (0.011)	0.050*** (0.017)
Size	0.073 (0.120)	0.096 (0.176)	0.160*** (0.021)	0.263*** (0.031)
Age	0.123 (0.456)	0.420 (0.667)	-0.004 (0.097)	-0.000 (0.000)
Liquid	0.004 (0.004)	0.005 (0.007)	-0.004 (0.097)	-0.000 (0.000)
Cash	-0.381 (0.315)	-0.317 (0.460)	0.092 (0.071)	0.140 (0.107)
Roa	-0.207 (0.331)	-0.248 (0.484)	0.221*** (0.057)	0.357*** (0.086)
Ocf	-0.175 (0.264)	-0.307 (0.387)	-0.143*** (0.053)	-0.233*** (0.080)
Dual	-0.060 (0.058)	-0.094 (0.085)	0.006 (0.011)	0.015 (0.017)
Constant	1.855 (1.577)	2.024 (2.307)	0.265 (0.408)	0.483 (0.614)
Firm/ Year/ Region/ Industry	Yes	Yes	Yes	Yes
N	1154	1154	25922	25922
R ²	0.025	0.022	0.009	0.008

Note: Standard errors are reported in parentheses. *** denotes statistical significance at the 1% levels, respectively.

Table 8 reports the regional heterogeneity analysis, in which digital transformation significantly promotes innovation in both the eastern and western regions. In the eastern region, the coefficients are 0.023 and 0.036, both of which are significant at 10%. The coefficients in the western region are 0.109 and 0.069, which are significant at the 5% and 1% levels. The coefficients for the central region are positive but insignificant.

This regional variation can be explained by the marginal effect of alleviating financing constraints. The financial markets in the eastern region are well developed, and information asymmetry is low. As a result, SMEs face relatively mild financing constraints, leaving limited scope for improvement through digital transformation, so the marginal contribution of digital transformation is therefore weaker in this region. In contrast, the western region is characterized by underdeveloped financial growth, and enterprises are facing severe long-term financing constraints. Digital transformation increases information transparency and creditworthiness, leading to a larger innovation-releasing effect.

Table 8. Regional heterogeneity.

Dependent Variables	(1) Eastern		(2) Central		(3) Western	
	Innov	Lndex	Innov	Lndex	Innov	Lndex
Digital	0.023* (0.012)	0.036* (0.018)	0.021 (0.029)	0.043 (0.043)	0.109** (0.040)	0.069*** (0.020)
Size	0.160*** (0.023)	0.262*** (0.035)	0.162*** (0.055)	0.258*** (0.081)	0.266*** (0.031)	0.275*** (0.039)
Age	0.150 (0.108)	0.245 (0.162)	-0.404* (0.243)	-0.643* (0.361)	0.024 (0.142)	-0.100 (0.164)
Liquid	-0.000 (0.000)	-0.000 (0.000)	-0.002** (0.001)	-0.003** (0.002)	-0.000 (0.000)	-0.001** (0.000)
Cash	0.085 (0.076)	0.147 (0.115)	0.104 (0.202)	-0.206 (0.300)	0.112 (0.104)	0.097 (0.138)
Roa	0.217*** (0.062)	0.357*** (0.094)	0.423*** (0.165)	0.625** (0.245)	0.341*** (0.085)	0.466*** (0.114)
Ocf	-0.149*** (0.058)	-0.245*** (0.087)	-0.140 (0.146)	-0.219 (0.217)	-0.235*** (0.078)	-0.231** (0.103)
Dual	-0.005 (0.013)	0.002 (0.019)	0.035 (0.027)	0.057 (0.040)	0.010 (0.017)	0.018 (0.019)
Constant	-0.216 (0.445)	-0.323 (0.669)	1.577* (0.814)	2.628** (1.209)	1.326 (1.356)	1.096 (0.726)
Firm/ Year/ Region/ Industry	Yes	Yes	Yes	Yes	Yes	Yes
N	20001	20001	4856	4856	2219	2219
R ²	0.010	0.009	0.015	0.014	0.016	0.009

Note: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Our findings confirm that digital transformation positively affects innovation in SMEs. The results are robust to endogeneity controls, variable replacement, and the exclusion of specific samples. The positive effect is partly due to the alleviation of financing constraints. Moreover, the impact varies greatly by ownership and region. Specifically, digital transformation has a more significant positive effect on innovation in non-SOEs than in SOEs, indicating that non-SOEs are more sensitive to the market, more flexible, and more willing to transform themselves. Regarding regional differences, the effect is strongest in the western region, followed by the eastern region, while the central region has positive but insignificant coefficients. This regional phenomenon can be explained by the marginal effect of alleviating financing constraints. In the western region, which is less developed in terms of finance, digital transformation has a significant effect on improving transparency and creditworthiness, thus resulting in a more significant innovation effect. In contrast, in the eastern region, which is relatively mature, financing constraints are relatively mild, and the marginal effect of digital transformation is therefore reduced.

5.2. Recommendations

The findings offer several policy implications: (1) Strengthen policy guidance and resource support: Governments should implement targeted policies for the digital transformation of SMEs, with tax incentives and technical grants to reduce the costs of transformation. In addition, governments should increase investment in digital infrastructure and collaborative technology platforms to promote digital development. (2) Differentiated and targeted support strategies should be implemented, such as strengthening digital infrastructure and inclusive finance in the western region to gain marginal benefits, guiding eastern enterprises to carry out deep intelligent upgrading, providing precise assistance in the central region, and giving priority to non-SOEs through subsidies and credit incentives. (3) Improve the digital-oriented financial service system and expand financing channels for enterprises. Regulators should guide commercial banks to accelerate the establishment of digital credit operations. Based on the operational data produced by the digital transformation of the companies, banks can build a new credit evaluation system and offer customized financial products, such as data pledge loans and special credit funds for digital transformation projects, to match the digital transformation cycle of SMEs. Digital operational data mitigates the information asymmetry between banks and enterprises, reduces the high requirements of traditional collateral and guarantees, effectively alleviates the financing constraints that hinder the innovation efforts of SMEs, and facilitates the capital flow from digital transformation to innovative output.

Despite its contributions, this study has several limitations. Even with the adoption of fixed-effects and IV estimations, residual endogeneity risks remain unaddressed. The sample coverage is limited to NEEQ-listed SMEs, restricting the generalizability of our findings to non-listed counterparts. These drawbacks lay out promising research directions for subsequent research.

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