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Digital Transformation and Corporate Innovation in SMEs

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Abstract

Whether and how digital transformation affects innovation in small and medium-sized enterprises (SMEs) remains to be examined. This study aims to answer this question using a sample of SMEs listed on the Chinese National Equities Exchange and Quotations (NEEQ) market from 2012 to 2023. Employing textual mining techniques, this paper measures the degree of digital transformation through keyword frequency analysis of annual reports, while innovation is measured by the number of patent grants. Panel fixed effects models show that digital transformation significantly enhances corporate innovation in SMEs. This relationship remains robust after comprehensive endogeneity and additional robustness tests. Mechanisms analysis reveals that digital transformation alleviates financial constraints and enhances supply chain diversity, enabling SMEs to allocate more resources toward innovation activities. Heterogeneity analysis reveals that the positive effect of digital transformation on innovation is more pronounced for firms located in cities with higher digital finance coverage, in midwestern regions, and in industries with lower digitalization levels. These findings shed light on the power of digital technology, highlighting how its adoption can significantly bolster the innovation capacity of SMEs and drive their growth in a rapidly evolving digital economy.

Keywords: digital transformation; innovation; SMEs; financial constraint; supply chain diversity

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1. Introduction

As the backbone of economic development, small and medium-sized enterprises (SMEs) contribute significantly to employment and GDP growth. However, SMEs constantly face survival challenges due to weak competitiveness and low productivity. In China, the average life cycle of SMEs is less than three years, with fewer than 7% surviving five years and fewer than 2% surviving ten years. To enhance SMEs' competitiveness, governments worldwide have encouraged digitalization initiatives. The COVID-19 pandemic has further accelerated the digital transformation trend among SMEs [1]. The report from the 20th National Congress of the Communist Party of China explicitly stated, "Accelerate the development of the digital economy, promote the deep integration of the digital economy with the real economy, and build internationally competitive digital industry clusters." According to the 2024 Report on Digital Transformation of Chinese Small and Medium-sized Enterprises, jointly published by Lenovo and 36Kr Research Institute, 98.8% of Chinese SMEs have initiated digital transformation. However, the majority (62.6%)

remain in the early stages of digitalization and have not yet entered the intelligent phase. This context raises a critical question: Does digital transformation enhance innovation capabilities in SMEs, and if so, through what mechanisms?

Digital transformation involves integrating big data, cloud computing, artificial intelligence (AI), and blockchain into SMEs' business models. These technologies improve firm performance and help SMEs better cope with the pandemic lockdown [1]. Digitalization benefits firms by enhancing corporate governance [2], decreasing information asymmetry [3], increasing total factor productivity [4], and raising market value [5]. A substantial body of literature has explored factors influencing SMEs' digital transformation. To improve the digitalization process, SMEs need to focus on digital technology investment, employee digital literacy, and digitalization strategies [6]. Therefore, financial resources are critical, as enterprises require substantial capital investment for digital infrastructure and human capital upgrading. Financial constraints significantly hinder SMEs' digital transformation efforts [7]. Management strategy, organizational structure, and corporate culture also affect the success of SMEs' digital transformation [8]. In addition, factors such as CEO educational background, firm size, and internationalization level are critical for SME digitalization [9].

Another stream of literature focuses on the benefits of digital transformation. Digital transformation enhances SMEs' core competitiveness and contributes to sustainable development [10], thereby improving firm performance [6]. The application of digital technologies makes information transmission more efficient and transparent. Subsequently, digitalization can promote SMEs' information disclosure quality, alleviate agency problems, and increase firm value [11]. Digital transformation also enhances SME resilience, particularly during crisis periods [12]. However, these studies primarily rely on questionnaire-based assessment of SME digitalization, which introduces inherent subjectivity in the measurement. Additionally, sample sizes are typically limited, and research on the relationship between SMEs' digital transformation and innovation remains scarce.

Recently, a few studies have shown that digital transformation acts as a catalyst for corporate innovation [13,14]. These studies identify several channels through which digital transformation promotes innovation: enhancing information transparency [15], increasing competitiveness, improving internal governance, and easing financing conditions [13,16,17]. Previous research demonstrates that digital transformation contributes to higher green innovation through enhanced R&D investment, optimized human capital allocation, and improved managerial efficiency [18,19]. Digital transformation increases green investment in high-polluting industries by alleviating financing constraints [20]. It enhances SMEs' innovation performance through human capital accumulation, information effects, and customer diversification [21]. Similarly, researchers find that digital transformation alleviates financing constraints, thereby improving SME innovation efficiency [22]. However, these studies are primarily based on the samples from the Chinese A-share listed market, which is dominated by large and medium-sized enterprises and cannot adequately represent SMEs. Therefore, whether these conclusions apply to SMEs requires further investigation.

It is difficult to theoretically determine ex ante how digitalization affects innovation in SMEs. On the one hand, compared with larger firms, SMEs typically face greater challenges when undergoing digital transformation. First, investment in digital technologies places SMEs under greater financial pressure [23], resulting in limited funding resources for R&D activities. Second, digitalization often requires significant business model adjustments for SMEs [24], leading to considerable uncertainties and potential innovation failures [9]. Third, SMEs may lack sufficient digital technology talent, which plays a key role in maximizing the benefit of digital transformation [14]. These factors suggest that digital transformation may hinder rather than promote SME innovation.

On the other hand, dynamic capabilities theory provides a theoretical foundation for expecting positive effects. The theory posits that a firm's success depends on its ability to continuously adapt to market conditions [25]. It highlights three core elements of dynamic capabilities: sensing, seizing, and transforming [26]. Digital transformation enhances coordination and complementarity among a firm's resources, capabilities, and technologies, driving the formation of a sustainable innovation ecosystem [27]. First, digital technologies improve information transparency, helping SMEs accurately sense market demand and technological trends. Second, digital technologies reshape SME resource configuration. Furthermore, digital technologies enhance supply chain management agility, enabling SMEs to rapidly adjust resource allocation and seize market opportunities. Therefore, based on the "sensing-seizing-transforming" theoretical framework, digital transformation has the potential to promote innovation in SMEs despite the aforementioned challenges. Consequently, whether and how digital transformation fosters corporate innovation in SMEs remains an open empirical question.

In this paper, we focus on SMEs from 2012 to 2023 in the Chinese National Equities Exchange and Quotations (NEEQ) market. This market was established specifically for Chinese SMEs, providing an ideal setting to address the research questions. Following previous studies [28], we measure the degree of digital transformation using frequencies of digital technology-related keywords in annual reports. We proxy corporate innovation capability with the number of patent grants. Our fixed effects models show that for every 1% increase in digital transformation, the number of total patent grants increases by 0.163%, which is significant at the 1% level. Digital transformation positively correlates with both invention patent grants and non-invention patent grants, demonstrating that digital transformation promotes innovation in SMEs. To address endogeneity concerns, we employ two-stage least squares regression (2SLS) with two instrumental variables (IV), respectively, including a Bartik IV and lagged digital transformation ($LnDigit_{i,t-1}$). These results confirm that digitalization promotes innovation in SMEs. We conducted several robustness tests to validate our findings, including excluding non-digitalized enterprises, using pre-pandemic data to exclude COVID-19 impacts, and analyzing the 2017–2023 sample to mitigate the effects of the 2015 stock market crash. Additionally, we substituted the dependent variable with alternative measures, including R&D investment ratio, R&D staff ratio, and the logarithm of patent applications plus one. All of these tests reaffirmed the robustness of our baseline conclusions. Mechanism tests reveal that digital transformation alleviates financing constraints and improves supply chain diversity, thereby improving firm performance and fostering innovation. Heterogeneity tests demonstrate that digitalization has a more pronounced innovation impact in cities with high digital finance coverage, in midwestern regions, and in industries with lower digitalization levels.

We contribute to the literature in three ways. First, this paper advances the understanding of how to promote SME innovation. Innovation is vital for SME high-quality development. Existing literature shows that innovation determinants include corporate governance, economic and financial development, policies and regulations, and culture [29]. Although several studies propose that digitalization fosters enterprise innovation, it is still unclear whether this relationship holds in SMEs. This study focuses on SMEs and provides evidence that digital transformation effectively promotes SME innovation, expanding research on SME innovation determinants. Our study differs from existing studies in two aspects [30]. First, we measure digitalization using text mining techniques, whereas previous studies used questionnaires. Second, we focus on Chinese SMEs, whereas Radicic and Petković (2023) studied German SMEs [30]. Given China's status as the largest developing country with distinct legal, institutional, and infrastructural characteristics compared to

developed countries, our conclusions provide deeper insights into leveraging digitalization to boost SME innovation in developing economies.

Second, this paper expands knowledge about the economic impacts of SME digitalization. Mainstream researchers primarily examine digitalization's economic effect using samples from A-share listed companies [13,29]. Some studies specifically address the impact of digitalization in SMEs on various aspects: promoting trade participation [31], promoting operating ability [1], increasing total factor productivity [32], and enhancing firm value [33]. This study finds that digitalization boosts innovation capabilities by alleviating financing constraints and enhancing supply chain management, thereby enriching the understanding of SME digitalization benefits. Third, our conclusions have important policy implications for maximizing enterprise digitization benefits through digital finance development. This paper extends dynamic capability theory from large enterprises to SMEs and identifies financing constraints and supply chain diversification as key mechanisms, supplementing the "sensing-seizing-transforming" theoretical framework from these two perspectives. We show that in cities with higher digital finance levels, the effect of digitalization on innovation is more pronounced. This suggests that governments should prioritize digital finance development to amplify the benefits of digital transformation.

2. Theoretical Foundation and Research Hypotheses

2.1. Digitalization and Innovation

The emergence of digital technology has fundamentally changed corporate innovation and entrepreneurship, particularly in terms of openness, affordance, and generativity [34]. Openness enables organizations to access external knowledge and resources, fostering collaboration and enhancing innovation outcomes. Affordance refers to the potential for action provided by digital tools, which lowers the barriers to innovation. Generativity describes the capacity of digital platforms to foster new ideas and innovations through cross-industry collaborations. According to the dynamic capability theory, SMEs can leverage resources, adapt to emerging challenges, and drive innovation in a rapidly evolving environment by sensing, seizing, and transforming opportunities. First, regarding openness, digital technology provides SMEs with easy-to-use tools for communication and collaboration, which improves both internal and external cooperation. Throughout the innovation process, openness facilitated by digital technology enables SMEs to better globalize [35], share information and knowledge with stakeholders. Openness increases SMEs' ability to perceive and integrate external resources. It enables SMEs to integrate external resources more efficiently in a global environment, accelerate the innovation process, and enhance competitiveness. This enhanced openness fosters cooperation and sparks new ideas. Therefore, digitalization accelerates the pace of innovation in SMEs and enhances corporate competitiveness [36].

Second, digitalization improves the operational capabilities of SMEs [37], enabling them to better utilize resources and thus enhancing affordance. In specific environments, affordance provides SMEs with the potential for action and lowers the barriers to innovation. Enhanced affordance enables SMEs to quickly adapt their products and services, thereby increasing the flexibility and efficiency of innovation efforts. Consequently, SMEs are better positioned to seize opportunities and enhance agility. This also enables data-driven decision-making that optimizes the innovation process and boosts overall efficiency. Third, digital technology harnesses the resources of various participants, thus increasing innovation generativity. Generativity allows enterprises from different industries to collaborate in the innovation process, creating an innovation network that enriches the pool of creative ideas. It also enhances SMEs' ability to reshape resources for innovation. Thus,

digitalization empowers SMEs to generate new ideas and solutions in rapidly changing environments. Based on this analysis, we propose the following hypothesis.

Hypothesis 1: *Digitalization promotes innovation in SMEs.*

2.2. Digitalization, Financial Constraints, and Innovation

SMEs often face significant challenges in obtaining funding, which are related to factors such as firm size, information opacity, lack of collateral, and low operational capabilities [35,38]. Financial constraints limit the ability of SMEs to secure funding, weakening R&D investment and innovation output. In theory, digital transformation can improve funding accessibility for SMEs in the following ways. First, the application of digital technology allows SMEs to effectively collect and share more multi-dimensional operational data. Big data increases the transparency of SMEs and enables potential capital providers to better understand the operating conditions and risks of SMEs. Thus, digital transformation increases the willingness of financial institutions and investors to provide funds to SMEs. This sensing capability allows SMEs to identify and access a broader range of financing opportunities.

Second, fintech companies can efficiently conduct credit assessments for SMEs by utilizing multi-dimensional data, including non-traditional information such as online behavior, transaction history, and customer evaluations [38]. That capability enables SMEs to seize the necessary funding for R&D and innovation activities. Third, digital marketing and e-commerce platforms help SMEs enhance their core competitiveness [39]. These platforms can improve brand awareness and increase financing attractiveness. This reshaping capability allows SMEs to become more competitive in the financing market, thereby easing funding constraints and ensuring a steady resource flow for continuous innovation.

Therefore, digital transformation can alleviate the financing constraints faced by SMEs. From the perspective of dynamic capability theory, digital transformation enhances SMEs' ability to perceive financing opportunities, seize available resources, and reshape market competitiveness. Big data analysis and financial technologies improve transparency and financing efficiency, while digital marketing and e-commerce platforms increase the market appeal and profit potential of SMEs. Collectively, these factors provide the financial support needed for R&D and innovation, accelerating the pace of innovation and strengthening competitiveness. Therefore, we present the following hypothesis.

Hypothesis 2: *By easing financing constraints, digitalization promotes innovation in SMEs.*

2.3. Digitalization, Supply Chain Diversity, and Innovation

Digitalization can reduce supply chain concentration and enhance the diversity of SME supply chains [40]. First, digital transformation enables SMEs to expand their supplier networks. Digital technologies allow SMEs to access a wider array of domestic and international suppliers, increasing procurement options and flexibility. Through big data analysis and digital platforms, digital transformation enables SMEs to sense and access broader networks of domestic and international suppliers. This enhanced sensing capability reduces dependence on single suppliers, increases procurement flexibility, and provides a richer resource base for innovation. Second, digitalization improves SMEs' capabilities for supply and demand analysis within the industrial chain. By leveraging big data and cloud computing, companies can monitor and analyze supply chain conditions in real-time, leading to better management of suppliers and customers [41]. Additionally, cloud computing and collaborative platforms facilitate information sharing and cooperation among supply chain members, which not only helps SMEs establish closer cooperative relationships with

suppliers but also allows them to obtain more favorable prices and conditions through collective procurement.

Increased supply chain diversity allows SMEs to reduce reliance on single or limited numbers of suppliers, thereby improving SMEs' supply chain resilience and enhancing their ability to withstand external shocks while ensuring survivability [42]. Furthermore, within a diverse supply chain network, SMEs can access a broader range of technologies and innovative practices. Different partners may introduce new technological solutions, process improvements, or other innovations that can be integrated into SMEs' products and services. Additionally, a diverse supplier network fosters cross-industry and cross-regional information exchange, enhancing firms' capacity to absorb external knowledge. According to dynamic capability theory, digital transformation enhances SMEs' ability to perceive supply chain opportunities, seize resource advantages, and reshape their innovation ecosystems. Big data and cloud computing reduce supply chain concentration by expanding supplier networks and optimizing supply chain management, while collaborative platforms facilitate the acquisition of innovative resources by promoting information sharing and cross-border cooperation. These processes enable SMEs to build more resilient and innovative supply chain networks, accelerate technology absorption and idea generation, and improve innovation performance. Consequently, we propose the following hypothesis.

Hypothesis 3: *Digitalization promotes innovation in SMEs by diversifying the supply chain.*

3. Data Source and Research Design

3.1. Data Source

Since the establishment of the NEEQ in 2012, our initial sample comprises all the NEEQ-listed firms spanning from 2012 to 2023. Patent grant data come from the CEER database (https://www.ccerdata.cn/). Annual reports are scraped from the NEEQ website using a Python 3.12.6 web crawler. Basic information variables are obtained from the China Stock Market and Research (CSMAR) database. Firm-level financial data are obtained from the Wind database. The growth rate of the Internet, which is used to construct the IV variable, comes from the China Statistical Yearbook. The breadth of digital finance is derived from the Digital Finance Research Center of Peking University. The following procedures are implemented to process the initial sample. Firstly, financial entities such as banks, securities firms, and insurance companies are excluded. Secondly, observations with missing data for key variables are eliminated. Finally, observations with negative book values of owner's equity are excluded. The final sample includes 60,542 firm-year observations. To avoid the influence of extreme values, continuous variables are winsorized at the 1% level.

3.2. Key Variables

The explained variable is corporate innovation output ($Innov_{i,t}$), calculated as the logarithm of the number of patent grants plus one. Innovation indicators are typically classified into two categories: innovation input and innovation output. Innovation input comprises R&D expenditure and the number of R&D personnel. Innovation output primarily includes the number of patent applications, patent grants, and patent citations. Considering that R&D data for NEEQ-listed companies exhibit significant missing values, as well as concerns regarding patent applications and citations, we use the number of patent grants to capture SMEs' innovation [43]. To approximate a normal distribution for the innovation variable and address the issue of zero patent grants for certain companies, following Li et al. (2020) [43], we add one to patent grant numbers and then apply a logarithmic transformation. Patent grants include total patent grants ($Patent_{i,t}$), invention patent grants

($Patent1_{i,t}$) and non-invention patent grants ($Patent2_{i,t}$). The higher the number of $Innov_{i,t}$, the greater the corporate innovation capability.

The explanatory variable is $LnDigit_{i,t}$, where $Digit_{i,t}$ is the total frequency of digitalization keywords for firm i in year t. The progress includes: First, the key words list of digitalization is built considering five aspects, including big data, cloud computing, artificial intelligence, blockchain, and other digital technologies application [28]. The key words list can be seen in Appendix A.1. Second, counting the number of keywords in the annual report. Then, $LnDigit_{i,t}$ is logarithmically processed by adding one to the number of the word frequency. Please refer to Wu et al. (2021) for more detailed information [28].

3.3. Model Setting

Since the panel fixed effects model can alleviate the endogeneity problem caused by omitted variables, it is widely used in corporate empirical research. To explore the impact of digital transformation on innovation in SMEs, referring to previous studies [43,44], we set the two-way fixed effects model as follows:

$$Innov_{i,t} = \beta_0 + \beta_1 LnDigit_{i,t} + \sum \beta_j * Controls_{i,t} + \delta_i + \lambda_t + \varepsilon_{i,t}$$

where i and t index firm and year, respectively. $\varepsilon_{i,t}$ is the error term. To mitigate the omitted variable problem, δ_i and λ_t are included in our model to capture the industry fixed effects and the year fixed effects, respectively. The explained variable is corporate innovation, including *LnPtent*, *LnPtent1* and *LnPtent2*. *Controls* is a vector of control variables containing the return on assets (*Roa*), firm size (*Size*), leverage ratio (*Lev*), cash flow from sales (*Cashflow*) and operating income (*Income*). Detailed definitions of variables are shown in Table 1. β_1 is the coefficient of interest, which is expected to be positive.

Table 1. Descriptive statistics.

Variable	Explanation	Obs	Mean	Std	Min	Max
Patent	Total number of patent grants	60,542	7.924	20.43	0.000	123.0
LnPatent	The logarithm of total patent grants plus one	60,542	0.875	1.373	0.000	4.820
LnPatent1	The logarithm of the number of invention patent grants plus one	60,542	0.442	0.849	0.000	3.496
LnPatent2	The logarithm of the number of non-invention patent grants plus one	60,542	0.691	1.272	0.000	4.654
LnDigit	The logarithm of digital transformation-related word frequency plus one	60,542	2.092	1.356	0.000	5. 160
Bigdata	The logarithm of big data-related word frequency plus one	60,542	0.379	0.769	0.000	5.921
Cloud	The logarithm of cloud computing-related word frequency plus one	60,542	0.409	0.814	0.000	5.746
AI	The logarithm of AI-related word frequency plus one	60,542	0.174	0.517	0.000	4.970
Blockchain	The logarithm of blockchain-related word frequency plus one	60,542	0.036	0.216	0.000	4.905
Other_Digit	The logarithm of word frequency of other kinds of digital technology plus one	60,542	1.953	1.286	0.000	6.700
Roa	Return on total assets	60,542	0.011	0.165	−0.887	0.315
Size	The logarithm of total assets	60,542	18.49	1. 227	15.30	21.62
Lev	The ratio of total liabilities to total assets	60,542	0.446	0.235	0.031	1.256
Cashflow	The ratio of operating cash flow to total assets	60,542	0.975	0.798	0.000	5.194
Income	The ratio of operating income to total assets	60,542	0.857	0.653	0.025	4.155

3.4. Descriptive Statistics

Table 1 shows the descriptive statistics. The mean and standard deviation of *Patent* are 7.924 and 20.43, indicating that there is a substantial variation in the innovation capabilities of SMEs listed on the NEEQ. The means of *LnPtent*, *LnPtent1* and *LnPtent2* are 0.875, 0.442, and 0.691, respectively. The mean of *LnDigit* is 2.092, with a standard deviation of 1.356, indicating that digital transformation varies greatly among SMEs.

4. Empirical Results

4.1. Baseline Regression

Table 2 shows the baseline regression results. Column (1) shows that the coefficient of *LnDigit* is 0.211 without control variables, which is statistically significant at the 1% level. After adding control variables, the core coefficient is 0.163 (significant at the 1% level), as shown in column (2). This indicates that for every 1% increase in digitalization, the total patent grants of SMEs increase by 0.163%. The coefficient represents a substantial economic effect. A one-unit increase in digital transformation is associated with a 1.29 increase in the number of total patent grants (calculated as $0.163 * 7.924$, where 7.924 represents the sample mean of the total number of patent grants). The coefficients for *LnPatent1* and *LnPatent2* are 0.093 and 0.151, respectively, both statistically significant at the 1% level. Column (5) incorporates firm fixed effects into the model based on column (2) to control for unobserved factors that are constant across industries and time but vary across firms. The estimated coefficient is 0.224, which is statistically significant at the 1% level. Overall, the baseline regression results demonstrate that digital transformation positively relates to innovation in SMEs.

Table 2. Baseline regression results.

Variable	(1) *LnPatent*	(2) *LnPatent*	(3) *LnPatent1*	(4) *LnPatent2*	(5) *LnPatent*
LnDigit	0.211 ***	0.163 ***	0.093 ***	0.151 ***	0.224 ***
	(0.007)	(0.007)	(0.005)	(0.007)	(0.010)
Roa	–	−0.297 ***	−0.266 ***	−0.208 ***	−0.452 ***
	–	(0.039)	(0.026)	(0.034)	(0.038)
Size	–	0.248 ***	0.160 ***	0.207 ***	0.391 ***
	–	(0.008)	(0.005)	(0.007)	(0.018)
Lev	–	−0.391 ***	−0.279 ***	−0.302 ***	−0.451 ***
	–	(0.034)	(0.022)	(0.031)	(0.042)
Cashflow	–	−0.042 ***	−0.019 **	−0.042 ***	0.001
	–	(0.015)	(0.009)	(0.014)	(0.017)
Income	–	0.040 **	0.011	0.048 ***	0.037
	–	(0.020)	(0.012)	(0.018)	(0.023)
Constant	0.434 ***	−3.876 ***	−2.575 ***	−3.319 ***	−6.653 ***
	(0.016)	(0.139)	(0.093)	(0.131)	(0.324)
Ind FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	Yes
R^2	0.206	0.246	0.213	0.224	0.554
Obs	60,542	60,542	59,012	58,997	60,542

Notes: Standard errors clustered at the firm level in parentheses. ** indicates *p*-value less than 5%, *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

4.2. Endogeneity Test

The baseline regression shows that digital transformation promotes firm innovation in SMEs. However, this conclusion could suffer from endogeneity. On the one hand, companies that possess stronger innovation capabilities are more likely to adopt digitalization,

which can create a reverse causality problem. On the other hand, despite incorporating fixed effects and control variables, the baseline model remains susceptible to the issue of omitted variables due to the multitude of factors influencing corporate innovation. The regression outcomes could be biased if omitted factors correlate with digitalization and innovation. Additionally, measurement error in digital transformation could further exacerbate the endogeneity problem.

To alleviate endogeneity, we employ 2SLS regression, and the results are shown in Table 3. Columns (1) and (2) present the results using *IV_Baritik* as the IV variable. *IV_Baritik* is a shift-share IV, calculated by multiplying the one lag of the mean *LnDigit* for other firms within the same industry and year by the growth rate of Chinese Internet penetration, following the methodology outlined in previous studies [13,45]. A valid instrumental variable must satisfy both the relevance and exogeneity assumptions. Since firm digitalization may be affected by other firms in the same industry, *IV_Baritik* meets the relevance assumption. Considering that the digitalization decision of a single firm is unlikely to affect the Internet growth rate, *IV_Baritik* satisfies the exogeneity assumption. In the first stage of regression, the Cragg-Donald Wald F statistic is 40.9, which is greater than Stock and Yogo's 10% critical value of 16.4 [46], implying no weak instrumental variable problem. In the second-stage regression, the coefficient of *LnDigit* is 2.096 (significant at the 1% level), suggesting the baseline conclusion still holds after addressing endogeneity concerns.

Table 3. Endogeneity test by 2SLS regression.

Variable	(1) First-Stage *LnDigit*	(2) Second-Stage *LnPatent*	(3) First-Stage *LnDigit*	(4) Second-Stage *LnPatent*
LnDigit	–	2.096 ***	–	0.196 ***
	–	(0.310)	–	(0.010)
IV_Baritik	−0.073 ***	–	–	–
	(0.010)	–	–	–
$LnDigit_{i,t-1}$	–	–	0.819 ***	–
	–	–	(0.003)	–
Controls	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Kleibergen-Paap rk LM statistic	52.5 ***	–	3451 ***	–
Cragg-Donald Wald F statistic	40.9	–	9100	–
	[16.4]	–	[16.4]	–
Obs	40,760	40,760	44,314	44,314

Notes: The growth rate of Internet penetration in China comes from the City Statistical Yearbook. The numbers in brackets represent the 10% critical value proposed by Stock and Yogo (2005) [46]. Standard errors clustered at the firm level in parentheses. *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

Columns (3) and (4) show the IV regression results using $LnDigit_{i,t-1}$ as the instrumental variable. $LnDigit_{i,t-1}$ satisfies the relevance assumption because of the autocorrelation of the variable. Given that $LnDigit_{i,t-1}$ is predetermined, it also satisfies the exogeneity assumption to some extent. The Cragg-Donald Wald F statistic in column (3) is significantly higher than Stock and Yogo's critical value, indicating $LnDigit_{i,t-1}$ is not a weak instrumental variable. The second-stage regression result shows that the coefficient of $LnDigit_{i,t-1}$ is 0.196 (significant at the 1% level), thereby supporting the baseline conclusion.

4.3. Additional Robustness Tests

The results of other robustness tests are shown in Table 4. Column (1) excludes firms that have not implemented digitalization. In column (2), we use data ranging from 2012 to 2019 to exclude the potential effects of the COVID-19 pandemic. The coefficient in column (2) is 0.044 and significant at the 1% level. We also conducted regression using data from 2020 to 2023 (shown in Appendix A.2); the core coefficient is 0.313 (significant at the 1% level). This indicates that digitalization has had a more pronounced effect on SME innovation in the post-pandemic era. During the second half of 2015, the Chinese stock market experienced a severe crash that persisted into 2016. To mitigate the impact of the stock market crash, in column (3), we use data from 2017 to 2023 to exclude its influence. The coefficient in column (3) is 0.204 (significant at the 1% level), which suggests that the conclusions from the baseline regression are not sensitive to the choice of sample period.

Table 4. Robustness tests.

Variable	(1) *LnPatent*	(2) *LnPatent*	(3) *LnPatent*	(4) *RD_ratio*	(5) *RD_Staff*	(6) *Pat_Appli*
LnDigit	0.161 ***	0.044 ***	0.204 ***	0.315 ***	1.362 ***	0.042 ***
	(0.007)	(0.006)	(0.008)	(0.095)	(0.111)	(0.006)
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cluster-level	Firm	Firm	Firm	Firm	Firm	Firm
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.247	0.228	0.250	0.051	0.391	0.104
Obs	59,175	36,828	45,585	47,083	47,589	34,421

Notes: *RD_ratio* refers to the ratio of R&D investment to total assets, expressed as a percentage. *RD_Staff* refers to the proportion of R&D staff to total staff. These two variables are from the CEER database. *Pat_Appli* is the logarithm of total number of patent applications plus one. Number of patent applications was compiled based on data from the China National Intellectual Property Administration. Standard errors clustered at the firm level in parentheses. *** represents *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

To ensure the robustness of the baseline results, we replace the dependent variable. In columns (4) and (5), the dependent variables are the ratio of R&D expenditure to total assets and the proportion of R&D employees to total employees, respectively. The coefficients in columns (4) and (5) are both significantly positive, indicating that the digital transformation of SMEs has led to increased investment in R&D resources and human capital, thereby promoting corporate innovation. In column (6), the natural logarithm of the total number of patent applications is used as the dependent variable. The coefficient in column (6) is significantly positive, indicating that digital transformation promotes patent applications. All robustness regression results in Table 4 demonstrate that digitalization promotes innovation in SMEs.

Given that variable measurement methods can significantly impact results, we modify the measurement approach for the explanatory variables to enhance the robustness of our findings. Specifically, we use the logarithm of the frequency of terms exclusively related to big data, cloud computing, artificial intelligence (AI), blockchain, and other digital technology applications as explanatory variables. The regression results are presented in Table 5. All the core coefficients are positive and significant at the 1% level, further supporting the robustness of the baseline conclusion.

Table 5. Replacing explanatory variables.

Variable	(1) *LnPatent*	(2) *LnPatent*	(3) *LnPatent*	(4) *LnPatent*	(5) *LnPatent*
Bigdata	0.122 ***	–	–	–	–
	(0.011)	–	–	–	–
Cloud	–	0.169 ***	–	–	–
	–	(0.011)	–	–	–
AI	–	–	0.219 ***	–	–
	–	–	(0.017)	–	–
Blockchain	–	–	–	0.181 ***	–
	–	–	–	(0.035)	–
Other_Digit					0.158 ***
					(0.007)
Controls	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
R^2	0.234	0.236	0.238	0.231	0.245
Obs	60,542	60,542	60,542	60,542	60,542

Notes: Control variables are added to all regressions. Standard errors clustered at the firm level in parentheses. *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

5. Mechanism Analysis

5.1. Easing Financial Constraints

Digital transformation can alleviate information asymmetry between SMEs and financial institutions. It helps financial institutions conduct risk assessments and improve financing approval processes. Moreover, digitalization can also improve the profitability of enterprises. Thus, digitalization may alleviate the financing constraints of SMEs. To verify this assertion, we employ two indicators to measure financial constraints.

The first indicator is the SA index, which is calculated based only on size and age [47]. The larger the value of the SA index, the greater the financing constraints. Compared with other indicators, the SA index has a stronger exogeneity and is therefore widely used in the literature. The regression results of the SA index on digitalization are shown in column (1) of Table 6. The coefficient of *LnDigit* is −0.004, which is significant at the 1% level, indicating that digital transformation effectively improves the financial conditions of SMEs.

For robustness, we also construct an FC index. This indicator is calculated based on six dimensions: cash ratio, size, establishment years, repayment ratio, fixed asset ratio, and profitability [43,48]. The construction process involves several steps. First, the six indicators are sorted, from high to low, and divided into five groups, and assigned values from 1 to 5. Subsequently, the scores of the five groups are summed and standardized to obtain the FC index. The larger the FC index, the more severe the financing constraints. Column (2) of Table 6 shows that digitalization significantly reduces the FC index. This evidence confirms the robustness of the finding that digitalization reduces financial constraint. Easing financing constraints helps enterprises invest more in R&D, thereby improving the funding conditions for innovation. This conclusion is largely consistent with previous research [43].

Table 6. Mechanism tests.

Variable	(1) *SA*	(2) *FC*	(3) *SupCon*	(4) *CusCon*	(5) *ChainCon*
	Financial constraint	Financial constraint	Supplier concentration	Customer concentration	Supply chain concentration
LnDigit	−0.004 ***	−0.003 ***	−0.416 ***	−0.347 ***	−0.360 ***
	(0.001)	(0.001)	(0.162)	(0.159)	(0.127)
Controls	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
R^2	0.795	0.8752	0.750	0.820	0.800
Obs	60,298	60,542	40,719	41,212	41,320

Notes: *SA* is the financial constraint index. Following Hadlock and Pierce (2010) [47], the equation is as follows: $SA = -0.737 * size + 0.043 * size^2 - 0.04 * age$, where *size* is the log of book assets in millions of yuan, and age represents the firm's establishment age. FC is calculated following Wang et al. (2015) [48]. *SupCon* is the supplier concentration, defined as the ratio of the purchases from the top five suppliers to total annual purchases. *CusCon* is the customer concentration, calculated as the ratio of sales to the top five customers relative to total annual sales. Supply chain concentration (*ChaiCon*) is the mean of *SupCon and CusCon*. Supply chain-related data are obtained from the CSMAR database. Standard errors clustered at the firm level in parentheses. *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

5.2. Improving Supply Chain Diversity

We explore whether digitalization enhances SMEs' innovation capabilities through the supply chain. Digital technologies enable SMEs to collaborate with a broader range of suppliers, thus lowering supplier concentration and operational costs while enhancing competitive pricing. Additionally, digital tools such as online platforms and e-commerce diversify SMEs' customer base and expand market reach. Thus, digitalization reduces dependency on a few key suppliers and customers [45,49]. Consequently, digitalization makes SMEs less vulnerable to market fluctuations by mitigating supplier and customer concentration risks, improving operational flexibility and firm performance, and creating a conducive environment for innovation.

In column (3) of Table 6, the dependent variable is supplier concentration, captured by the ratio of purchases from the top five suppliers to total purchases. The coefficient of *LnDigit* is −0.416, which is significant at the 1% level, indicating that digitalization reduces the supplier concentration of SMEs. We also measure customer concentration using the ratio of sales to the top five customers relative to total sales. The coefficient in column (4) is −0.347 (significant at the 1% level), indicating that digitalization also lowers customer concentration. In column (5), the dependent variable is the supply chain concentration, which is the mean of supplier concentration and customer concentration. For robustness, we also regress the proportion of the largest supplier and the proportion of the largest customer on digitalization, and the results remain consistent (results are shown in Appendix A.2). These results demonstrate that digitalization has significantly reduced the supply chain concentration of SMEs. In other words, digitalization has increased the diversity of supply chain choices for SMEs. This finding aligns with those of Li et al. (2023) [50].

6. Heterogeneity Tests

6.1. Heterogeneity of Digital Finance

In recent years, the advent of digital finance has revolutionized the financial landscape in China, particularly for SMEs [51]. The expansion of digital finance has not only provided SMEs with additional financing channels but has also improved funding availability, particularly in areas traditionally underserved by conventional banks [52]. On the one hand, digital finance has transcended the geographical limitations and information asymmetries

of traditional banking by leveraging information technologies, thereby making it easier for SMEs to secure financing. On the other hand, digital finance has increased financing efficiency [53]. Using big data technologies, financial institutions can assess the credit risks of borrowing enterprises more accurately, thereby reducing approval times. Furthermore, digital finance offers flexible funding solutions that cater to the diverse needs of SMEs. Therefore, digital finance has significantly enhanced the financing conditions for SMEs.

In the previous section, we highlighted that financing constraints constitute a crucial mechanism through which digitalization influences innovation. Therefore, we anticipate that in regions where digital finance is more developed, the impact of digitalization on SME innovation will be even stronger. We divide the sample into two groups using the median of digital finance coverage in prefecture-level cities. The regression results are shown in columns (1) and (2) of Table 7. As expected, in the subsample with a high level of digital finance development, the coefficient of *LnDigit* is 0.247, while the coefficient for the low-level group is only 0.054. Therefore, digital finance plays a crucial role in the effect of digitalization on innovation. This result corroborates the role of financing constraints as an influencing mechanism.

Table 7. Heterogeneity tests.

Type	(1) High	(2) Low	(3) Eastern	(4) Midwestern	(5) High	(6) Low
	Coverage of digital finance		Region		Industry digitalization	
LnDigit	0.247 ***	0.054 ***	0.157 ***	0.178 ***	0.113 ***	0.201 ***
	(0.011)	(0.007)	(0.008)	(0.013)	(0.008)	(0.010)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.260	0.235	0.250	0.248	0.156	0.228
Obs	28,044	28,147	43,222	17,320	28,536	31,955
Diff	0.193 ***		−0.021 ***		−0.088 ***	

Notes: The breadth of digital finance is derived from the Digital Finance Research Center of Peking University. Industry digitization is the average digitization level of A-share listed companies in the respective industry, classified based on the industry categories of the China Securities Regulatory Commission (2012 edition). The digitization level of A-share companies is measured using the same text analysis method. Diff represents the difference between the left and right sides. Its statistic is calculated using the bootstrap method, employing sampling without replacement with 500 replications. Standard errors clustered at the firm level in parentheses. *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

6.2. Regional Heterogeneity

China's economic development exhibits regional imbalance. First, the economic development of the eastern region outpaces that of the central and western regions. The eastern region leads in terms of GDP growth, industrial structure, and foreign investment attraction. Second, the information infrastructure in the eastern region is more comprehensive. In terms of network coverage, data centers, and digital applications, the eastern region has created more favorable conditions for SMEs' digital transformation. Third, financial development in the eastern cities also surpasses that in the central and western regions. Finally, the supply chain ecosystem in the eastern region is more developed, forming a more efficient supply chain system. These factors collectively contribute to the varying levels of digitalization across SMEs in China [54]. From the perspective of financing constraints, digital transformation can provide more funding resources for SMEs in the central and western regions. Therefore, we expect that the impact of digitalization on SMEs' innovation will be more significant in the central and western regions. The regional heterogeneity test results are shown in columns (3) and (4) in Table 7. The regression coefficient for enterprises in the eastern region is 0.157, while the coefficient for the western region is 0.178. The

difference is 0.021 and is statistically significant at the 1% level. These results are consistent with the expectations stated earlier.

6.3. Heterogeneity of Industry Digitalization

There are significant differences in the level of digitalization across various industries. In sectors with lower digitalization, companies can quickly gain competitive advantages through digital transformation. This is because implementing digital transformation helps SMEs improve operational efficiency, reduce production costs, and enhance customer experience, thereby attracting more customers and gaining greater market share [3]. Consequently, in industries with lower digitalization, SMEs' digital transformation will significantly enhance competitiveness. Therefore, we expect that in industries with lower digitalization levels, SMEs' innovative effects following digital transformation will be more pronounced. We divide the sample using the industry's digitalization level based on the sample median. The regression results are shown in columns (5) and (6) in Table 7. In industries with low digitalization levels, the innovative effect of digitalization is 0.201, while in industries with high digitalization levels, the innovative effect of digitalization is 0.113, which is consistent with our expectations.

7. Conclusions

Innovation serves as a key driver of high-quality development for SMEs, particularly when facing increasing market challenges. With the rapid advancement of information technology, digital transformation has become an essential trend for SMEs to adapt to market changes. While some studies suggest that digitalization may play a role in fostering innovation [29], it remains unclear whether this relationship holds for SMEs specifically. This paper addresses this gap by providing empirical evidence from a sample of NEEQ-listed SMEs over the period 2012–2023, demonstrating that digital transformation significantly promotes innovation in SMEs. This conclusion remains robust after a series of comprehensive robustness tests. Our findings align with prior research on digitalization as a driver of organizational innovation [13,14].

However, our study extends current understanding in several important ways. First, we introduce an innovative approach to measuring SME digitalization through text mining, while previous studies typically relied on surveys or questionnaires [21,22,38]. Second, we focus on Chinese SMEs, providing insights into the digital transformation of SMEs in a developing country context. This contrasts with studies such as Radicic and Petković (2023), which examined digital transformation in German SMEs [30]. Given China's unique legal, institutional, and infrastructural characteristics, our findings offer valuable insights for developing economies seeking to leverage digitalization to promote SME innovation. Third, our study also extends the literature by identifying specific mechanisms—easing financing constraints and enhancing supply chain variety—through which digitalization fosters innovation in SMEs.

From a theoretical perspective, this research contributes to dynamic capabilities theory (DCT) by demonstrating how digital transformation serves as a dynamic capability for SMEs. Digitalization enables SMEs to sense market opportunities through data-driven insights, seize these opportunities by optimizing financing and supply chain processes, and transform their operational capabilities to sustain innovation in dynamic environments. This extends DCT's application to resource-constrained SMEs, highlighting how digital capabilities act as strategic resources that enhance competitive advantage, particularly in regions or industries with lower digital maturity. Additionally, this research reveals that the effects of digitalization on innovation are heterogeneous. Digitalization better promotes innovation for firms in cities with high digital finance coverage, in midwestern regions, and

in industries with low digitalization levels. This heterogeneity in digitalization's effects further refines DCT by illustrating how external digital infrastructure and contextual factors shape capability development. From a practical standpoint, these findings have significant implications for SME managers and policymakers. Managers can leverage digital tools to enhance innovation through improved financing access and supply chain collaboration. Policymakers should prioritize targeted digital infrastructure investments, especially in underdeveloped regions, to foster equitable innovation growth.

Based on these insights, we propose the following recommendations. For SMEs, first, they should integrate digitalization into their core strategy to improve operational efficiency. Second, SMEs should actively prevent data silos and promote digital collaboration across supply chains. Third, SMEs should leverage digital finance solutions to optimize their accounts receivable financing processes. For policymakers, first, digital policies that prioritize investments in digital infrastructure should be implemented with regional differentiation. Policymakers should focus on reducing digitalization costs for SMEs and creating an environment that fosters innovation. Second, policies should encourage SMEs to embark on digital transformation initiatives by raising awareness and providing the necessary resources to facilitate digital adoption. Third, it is critical to foster an environment conducive to the growth of fintech, thereby amplifying the impact of digitalization on innovation. Fourth, policymakers should address financing constraints by ensuring convenient access to financing for SMEs during digital transformation. For the financial sector, developing a credit evaluation system based on digitalization levels to reduce financing barriers for SMEs is critical. At last, universities and research institutions should establish mechanisms for the swift translation of digital technology research into practical solutions for SMEs.

This study has several limitations. Firstly, the conclusions depend on the accuracy of our measurement of digital transformation. With advances in technology, future research could explore the use of large language models for more precise measurement of digital transformation in SMEs. Secondly, future studies could consider identifying quasi-natural experiments related to SME digital transformation to better address endogeneity issues. Lastly, the findings of this study are limited to the Chinese context. Given China's unique digital transformation process, further research is needed to examine whether these conclusions are applicable to other developing countries.

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Appendix A

Appendix A.1. Keywords Used for Measuring Digitalization

Type	Keywords
Big data	Big data, data mining, text mining, data visualization, heterogeneous data, credit reporting, augmented reality, mixed reality, virtual reality, data science
Cloud computing	Cloud computing, stream computing, graph computing, in-memory computing, multi-party secure computing, brain-like computing, green computing, cognitive computing, converged architecture, billion-level concurrency, EB-level storage, Internet of Things, cyber-physical systems, virtualization
Artificial intelligence	Artificial intelligence, business intelligence, image understanding, investment decision support system, intelligent data analysis, machine learning, deep learning, intelligent robots, semantic search, biometric technology, face recognition, voice recognition, identity verification, autonomous driving, natural language processing
Blockchain	Blockchain, digital currency, distributed computing, differential privacy technology, smart financial contracts
Other kinds of digital technologies	Mobile Internet, Industrial Internet, Mobile Internet, Internet Medical Care, E-commerce, E-commerce, Official Account, Mini Program, APP, Live Broadcast, Mobile Payment, Third-party Payment, NFC Payment, B2B, B2C, C2B, C2C, O2O, Online and Offline, Online Banking, Intelligence, Smart Wearables, Smart Animal Husbandry, Smart Animal Husbandry, Smart Agriculture, Smart Logistics, Smart Customer Service, Smart Cultural Tourism, Smart Environmental Protection, Smart Marketing, Digital Marketing, Unmanned Retail

Appendix A.2. Other Robustness Tests

Variable	(1) *LnPatent*	(2) *SupCon2*	(3) *CusCon2*
LnDigit	0.313 ***	−0.250 *	−0.330 **
	(0.014)	(0.152)	(0.155)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Cluster-level	Firm	Firm	Firm
Controls	Yes	Yes	Yes
R^2	0.248	0.708	0.723
Obs	23,713	40,719	41,212

Notes: Data used in column (1) ranges from 2020 to 2023. SupCon2 is the ratio of the purchases from the largest supplier to total annual purchases. CusCon2 is the ratio of the sales to the largest customer relative to total annual sales. Supply chain-related data are obtained from the CSMAR database, * indicates *p*-value less than 10%, ** indicates *p*-value less than 5%, *** indicates *p*-value less than 1%. Ind FE and Year FE represent industry fixed effects and year fixed effects, respectively.

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