

The Impact of Digital Innovation Capability on the Digital Innovation Performance of Science and Technology–Based SMEs: Mediating Effect of Open Innovation

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Abstract

In the digital economy era, the construction of digital innovation capability has become a crucial factor for firms to achieve a sustained competitive advantage. The innovation paradigm has also shifted from closed innovation to open innovation, involving collaboration between firms and external entities. This study aimed to study: 1) the current status of digital innovation capability, open innovation, and digital innovation performance of science and technology–based small and medium–sized enterprises (SMEs); 2) the impact of digital innovation capability on digital innovation performance; and 3) the mediating role of open innovation in this relationship. The sample consisted of science and technology–based SMEs in Shanxi Province, China, and was selected through stratified random sampling. Questionnaires using a five–point Likert scale were disseminated to firm managers via online platforms for data collection, and a total of 400 valid questionnaires were collected. Descriptive statistics and structural equation modeling (SEM) were employed for data analysis. The findings revealed that: 1) reorganization innovation capability had the highest mean value (3.86), followed by digital agility capability (3.77) and digital foundational capability (3.72); 2) all three dimensions of digital innovation capability positively influenced digital innovation performance, with digital agility capability having the most significant impact ($\beta=0.25$); 3) open innovation significantly mediated the relationships between all dimensions of digital innovation capability and digital innovation performance, with mediating effect values of 0.053, 0.079, and 0.042, respectively. These findings have both theoretical and practical significance for guiding science and technology–based SMEs in China to implement digital innovation.

Keywords: digital innovation capability, open innovation, digital innovation performance, science and technology-based SMEs, structural equation modeling (SEM)

Introduction

With the rapid development and widespread application of digital technologies such as big data, cloud computing, and the Internet of Things (IoT), digital innovation has emerged as a dominant trend in innovation. (Berawi et al., 2020; Chan, 2020). The continuous evolution and advancement of digital technologies have led to an increasing demand for firms to not only possess digital resources but also establish corresponding innovation capabilities to creatively reorganize these resources. (Nasiri et al., 2023). Digital innovation capability, which enables firms to leverage digital resources and facilitate their creative recombination, has become a key factor in gaining a competitive advantage in the digital economy. (Yang et al., 2021).

In China, science and technology-based small and medium-sized enterprises (SMEs) play a significant role in promoting digital innovation. These firms rely on a certain number of scientific and technical personnel to engage in research and development activities, obtain independent intellectual property rights, and convert them into high-tech products or services. (Morales et al., 2022). They account for 78% of the total number of patents and over 80% of the total number of product research and development (MIIT, 2022). However, science and technology-based SMEs face significant challenges in their innovation activities, including weak digital infrastructure, high digitalization costs, and a shortage of digital talent. Cultivating digital innovation capability in a targeted manner is crucial for their innovative development. Currently, academic research on digital innovation capability is still in its infancy, particularly regarding the lack of a unified framework for measuring the dimensions of digital innovation capability. (Kroh et al., 2024). Empirical research on the relationship between digital innovation capability and firm digital innovation performance is relatively scarce, and often overlooks science and technology-based SMEs. Therefore, it is imperative to explore the type of digital innovation capability that science and technology-based SMEs need to develop and whether digital innovation capability can enhance firm digital innovation performance.

In the current context of digital economic development, the network environment in which science and technology-based SMEs operate has undergone tremendous changes. Relying solely on internal R&D as a source of innovation is no longer sufficient to meet their development needs.

The boundlessness, fluidity, and flexibility of digital technologies have led to a trend toward cross-industry and multi-subject innovation in innovation activities (Brock et al., 2020), bringing new strategic opportunities for firms' open innovation (Nambisan et al., 2018). For science and technology-based SMEs with insufficient resources, seeking external support through open innovation is of great significance for their digital innovation. However, digital technologies enable strong connections that allow science and technology-based SMEs to access more available resources. Therefore, it is essential to determine whether science and technology-based SMEs still require open innovation and whether open innovation has a significant impact on the relationship between digital innovation capability and firm digital innovation performance.

Shanxi Province is a central traditional energy-producing province in China, renowned for its abundant coal resources. As a result, its economy primarily relies on coal mining and related industries. As China continues to advance green development and strive toward carbon neutrality, Shanxi Province is at a critical juncture in its economic transformation. (Zhang et al., 2022). Science and technology-based SMEs play a crucial role as key drivers of digital transformation, facilitating the transition from traditional development models to innovation-driven development models. The Shanxi Provincial Government has introduced a series of policies to support science and technology-based SMEs in enhancing their digital innovation; however, the level is still lower than that of other provinces.

Based on the above background analysis, this study draws on the resource-based view and dynamic capability theory, focusing on digital innovation capability, with open innovation as a mediating variable, to construct a theoretical model linking digital innovation capability, open innovation, and digital innovation performance. Through questionnaire surveys and SEM, the study empirically examines the influence of these three factors. The research findings not only expand traditional strategic theory research in the digital economy era but also guide science and technology-based SMEs in China to better understand and build digital innovation capability, as well as provide evidence for actively improving digital innovation performance through open innovation.

Research Objectives

In this study, the following research objectives are anticipated to be achieved:

1. To examine the current status of digital innovation capability, open innovation, and digital innovation performance of science and technology-based SMEs in Shanxi, China.
2. To identify the impact of digital innovation capability on the digital innovation performance of science and technology-based SMEs in Shanxi, China.
3. To explore the mediating role of open innovation in the relationship between digital innovation capability and the digital innovation performance of science and technology-based SMEs in Shanxi, China.

Scope of Research

Geographic Scope. This study focuses on Shanxi Province, situated in northern China. It is a central traditional energy-producing region in China, known for its abundant coal resources.

Population and Sample Scope. The science and technology-based SMEs used in this study are primarily based on the roster published by the Department of Science and Technology of Shanxi Province, covering seven industries: information technology, biotechnology, green technology, electronic information, artificial intelligence, financial technology, and agricultural science and technology. These firms have no more than 500 employees, annual sales revenues not exceeding 200 million yuan, and total assets not exceeding 200 million yuan.

Content Scope. First, this study assessed the current status of digital innovation capability, open innovation, and the digital innovation performance of science and technology-based SMEs in Shanxi, China. Second, this study examined the impact of digital innovation capability on a firm's digital innovation performance. Finally, this study examined the mediating role of open innovation in the relationship between digital innovation capability and a firm's digital innovation performance.

Time Scope. The research initiation phase began in January 2024, in the post-pandemic era, when the digital economy was severely impacted. Following the pretest, the official survey commenced in October 2024 and lasted for two months.

Literature Reviews

Resource-based view and Dynamic capability theory

The Resource-Based Theory (RBT), also known as the Resource-Based View (RBV), has emerged as one of the most influential and widely recognized frameworks for elucidating the sources of organizational competitive advantage (Barney, 1991). This theory posits that a firm's competitive advantage is derived from its unique resources, which are characterized by being valuable, rare, inimitable, and non-substitutable. Capability, as an intangible resource, is integral to the foundation of digital innovation. Consequently, RBV serves as a suitable theoretical lens to elucidate the critical role of digital innovation capability in enabling firms to achieve a competitive advantage.

The Dynamic Capability Theory (DCT) can be regarded as an extension of RBV, shifting the research perspective from a static to a dynamic one. According to this theory, firms can adapt to a dynamically changing external environment by integrating, constructing, and restructuring both internal and external resources, thereby achieving a sustainable competitive advantage. (Teece et al., 1997). Dynamic capability is composed of three key components: sensing, seizing, and transforming. Sensing refers to the ability of firms to detect external opportunities and threats; Seizing denotes the ability of firms to allocate and utilize resources to seize development opportunities or counteract threats; Transforming signifies the ability of firms to update and redeploy resources continuously. (Teece, 2007). In the post-pandemic era, firms are operating in a volatile, uncertain, complex, and ambiguous environment, marked by uncertainty and dynamic change. DCT offers a suitable theoretical framework for understanding how firms achieve a sustainable competitive advantage through open innovation.

Digital Innovation Capability and Digital Innovation Performance

Digital innovation capability refers to a firm's ability to utilize and deploy its resources to achieve business model, product, and service innovation, facilitated by digital technologies (Annarelli et al., 2021). Previous studies have explored the dimensions of digital innovation capability from various perspectives (Li et al., 2019; Liao, 2023; Yang et al., 2021), yet a theoretical consensus remains elusive. Drawing on the research of Yang et al. (2021) and Liao et al. (2023), this study categorizes digital innovation capability into three dimensions: digital foundational capability, digital agility capability, and reorganization innovation capability, with a focus on the acquisition, integration, and utilization of digital resources. This classification aligns

with the sensing, seizing, and transforming capabilities emphasized in DCT. Specifically, digital foundational capability refers to a firm's ability to utilize digital infrastructure to connect, aggregate, and intelligently analyze digital resources (Haefner et al., 2021; Z. Wang et al., 2023). Digital agility capability refers to a firm's ability to quickly reconfigure digital resources to detect and capitalize on opportunities (Duvivier & Gupta, 2023). Reorganization innovation capability refers to the ability to create new value by reorganizing digital resources through connections across value spaces (Henfridsson et al., 2018). Digital innovation performance measures the efficiency and effectiveness with which digital technologies enhance products, services, and value creation processes (Ardito et al., 2021; Boeker et al., 2021). Research on the factors influencing digital innovation performance is relatively limited. Existing studies have examined information technology (Tang et al., 2023), digital infrastructure (Bañares & Altmann, 2018), and digital platforms (Jiang et al., 2023; N. Wang et al., 2023), but they have largely overlooked the differences in firm capabilities.

First, digital foundational capability is categorized as a process layer capability, emphasizing the management of digital resources by firms to stimulate digital innovation. Du et al. (2024) confirmed that digital infrastructure has a significant impact on promoting innovation. (Du & Wang, 2024). Khalil et al. (2023) examined the positive influence of big data analytics capabilities on hotel performance. (Khalil et al., 2023). According to DCT, integrating internal and external resources is a crucial means of enhancing firm performance. Therefore, hypothesis H1a is proposed:

H1a: Digital foundational capability has a positive influence on the digital innovation performance of science and technology-based SMEs.

Second, digital agility has emerged as a key factor for organizations to address digital challenges. (Duvivier & Gupta, 2023; Salmela et al., 2022). Kő et al. (2022) explored how digital agility positively affects the innovation performance of SMEs by dynamically adjusting their strategies in response to user needs and market fluctuations. (Kő et al., 2022). Given that digital innovation performance is a subtype of innovation performance, and building on the logic of opportunity, hypothesis H1b is proposed:

H1b: Digital agility capability positively influences the digital innovation performance of science and technology-based SMEs.

Third, a high-level reorganization innovation capability helps firms in promoting the optimal allocation of data resources to create value. (X. Wang et al., 2023), ultimately achieving outstanding performance. The RBV considers that firms are an assemblage of different types of resources, and the effective utilization of unique resources is the cornerstone of building competitive advantages. Based on value logic, hypothesis H1c is proposed:

H1c: Reorganization innovation capability positively influences the digital innovation performance of science and technology-based SMEs.

Digital innovation capability and open innovation

Open innovation is a process in which firms accelerate innovation and effectively commercialize new ideas through the flow of internal and external knowledge. (Chesbrough, 2003). First, establishing extensive partnerships with external stakeholders is a prerequisite for open innovation. Audretsch et al. (2023) discussed how digital foundational capability enables firms to overcome spatial and temporal barriers, thereby enhancing the exchange of knowledge by leveraging digital infrastructure to facilitate external linkages. (Audretsch & Belitski, 2023). Hence, hypothesis H2a is proposed:

H2a: Digital foundational capability has a positive influence on open innovation.

Second, the dynamic nature of external collaboration in open innovation demands a high degree of adaptability from firms. Urbinati et al. (2020) argued that digital agility enables firms to capture new technologies and market demands more effectively, as well as to collaborate with external partners quickly. (Urbinati et al., 2020). Hence, hypothesis H2b is proposed:

H2b: Digital agility capability has a positive influence on open innovation.

Third, reorganization innovation capability enables firms to quickly adjust and restructure resources in response to market changes and customer needs, helping them better cope with uncertainty in the open innovation process. (Soluk et al., 2021). Accordingly, hypothesis H2c is made:

H2c: Reorganization innovation capability has a positive influence on open innovation.

Open innovation and digital innovation performance

Open innovation enables firms not only to compensate for the insufficiency of internal resources by accessing valuable technologies, knowledge, and insights from external digital resources but also to optimize resource utilization through various models. Roldan et al. (2022) investigated that open innovation drives innovation performance in the financial sector. (Roldan

Bravo et al., 2022). Based on sample data from 347 firms, N. Wang et al. (2023) empirically demonstrated that when internal open innovation and external open innovation grow in a balanced manner, the innovation effect is better (N. Wang et al., 2023). Therefore, hypothesis H3 is proposed:

H3: Open innovation has a positive influence on the digital innovation performance of science and technology-based SMEs.

The mediating role of open innovation

Prior studies have explored the mediating role of open innovation in the relationship between capabilities and performance. Rumanti et al. (2022) used the partial least squares structural equation modeling (PLS-SEM) method to confirm that open innovation plays an intermediary role in the relationship between innovation capabilities and the performance of batik SMEs (Rumanti et al., 2022). Similarly, Lee et al. (2023) investigated the mediating role of inbound and outbound open innovation in the relationship between digitalization capability and sustainable performance (Lee & Roh, 2023). Through open innovation, firms can quickly integrate emerging technologies and insights, as well as utilize a broader range of external resources, to enhance their market competitiveness (Duvivier & Gupta, 2023; Wu et al., 2022). Therefore, the following hypotheses are put forward:

H4a: Open innovation mediates the relationship between digital foundational capability and the digital innovation performance of science and technology-based SMEs.

H4b: Open innovation mediates the relationship between digital agility capability and the digital innovation performance of science and technology-based SMEs.

H4c: Open innovation mediates the relationship between reorganization innovation capability and the digital innovation performance of science and technology-based SMEs.

To sum up, from the perspective of the RBV, digital innovation capability can be regarded as an important resource for science and technology-based SMEs, conforming to the valuable, rare, inimitable, and non-substitutable (VRIN). Drawing on the DCT, science and technology-based SMEs can continuously optimize internal and external digital resources through open innovation, thereby creating greater value. Grounded in these theories, this study constructed a conceptual framework (Figure 1).

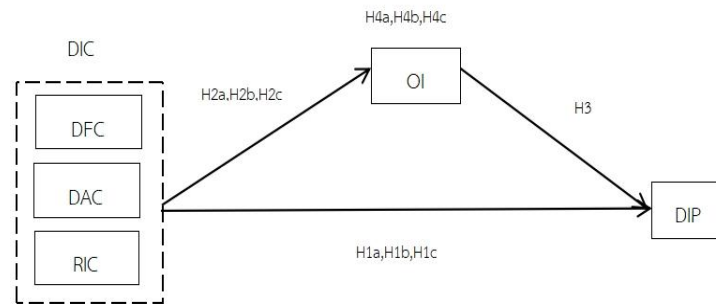


Figure 1: Conceptual framework and hypotheses

Note: DIC=digital innovation capability, DFC=digital foundational capability, DAC=digital agility capability, RIC reorganization innovation capability, OI=open innovation, DIP=digital innovation performance.

Research Methodology

This study adopted a quantitative research methodology to investigate the relationships among digital innovation capability, open innovation, and digital innovation performance. Prior to the survey, the author ensured that all participants fully understood the study's purpose and procedures, as well as their right to participate voluntarily, and obtained their informed consent by having them sign an informed consent form.

Population and samples

The population in this study is science and technology-based SMEs from Shanxi Province, China. By the end of 2023, a total of 6189 science and technology-based SMEs were registered in the Shanxi Province database. Yamane's formula was applied to determine the minimum sample size with a 95% confidence level. (Yamane, 1973), where n is the sample size, N is the population size, and e is the sampling error (0.05). The calculation formula and process are as follows:

$$n = \frac{N}{1 + Ne^2} = \frac{6189}{1 + 6189 * 0.05^2} \approx 375$$

To ensure the accuracy and reliability of the survey results, the final sample size was 400. Considering that the innovative capabilities of science and technology-based SMEs vary across different industries, stratified sampling was employed to ensure the representativeness of the

sample. The results were as follows: Information Technology (94), Biotechnology (56), Green Technology (40), Electronic Information (75), Artificial Intelligence (55), Financial Technology (14), and Agricultural Science and Technology (66).

Variable measurement

A five-point Likert scale was used to measure the variables, ranging from “strongly disagree (1)” to “strongly agree (5)”. To ensure robust content validity, well-established scales were adapted, and localized modifications were made. Specifically, DFC was measured by four items adapted from Lenka et al. (2017) and Liao et al. (2023); DAC was assessed using four items derived from Teece et al. (2007); RIC was measured using three items following the approach of Soluk et al. (2021); OI was evaluated using eight items adopted from Hung et al. (2013); and DIP was measured using ten items based on Tang et al. (2023).

Data collection

Data were collected from firm managers via WeChat or e-mail, with one manager selected from each firm. Prior to the formal survey, three experts were invited to provide feedback on the questionnaire. After revisions were made, a pretest was conducted on 10% of the total sample size. The formal questionnaire was then distributed, and a total of 400 valid questionnaires were collected.

Data Analysis

After the data were cleaned and coded, a series of analyses was performed. Reliability was tested with the value of Cronbach’s alpha (>0.7) (Nunnally, 1978). Validity, including convergent and discriminant validity, was tested using confirmatory factor analysis (CFA) in AMOS 24.0 with the values of factor loading (>0.7), composite reliability (>0.7), and average variance extracted (>0.5) (Hair et al., 2010).

Additionally, Harman’s single-factor test was employed to assess the extent of standard method variance to ensure the accuracy of study results (Podsakoff et al., 2003). Descriptive statistics were performed to examine the individual characteristics of the sample and the current status of digital innovation capability, open innovation, and digital innovation performance, using frequency and mean. Correlation analysis was employed to assess the strength and direction of the linear relationship between variables, using the Pearson correlation coefficient (r), which ranges from -1 to 1 .

Structural Equation Modeling was used to construct comprehensive models that incorporate both latent variables and observed variables (Kline, 2023). The parameters of the model were estimated using the maximum likelihood method (Murshudov et al., 1997). Then, path analysis and the bootstrap method were employed to test the research hypothesis.

Research Results

Individual Characteristics of the Sample

The individual characteristics of the sample revealed a nearly equal gender distribution, with 51.0% of the respondents being male and 49.0% female. Regarding the position, the majority of participants were senior managers (64.3%), followed by middle managers (25.0%) and junior managers (10.7%). In terms of firm size, 49.3% of the firms had 50–100 employees, 34.0% had fewer than 50 employees, and 16.8% had 101–500 employees. Overall, the sample was diverse and representative of the population.

Reliability and Validity

As shown in Table 1, all variables exhibited Cronbach's alpha values exceeding the standardized threshold of 0.7, indicating strong internal consistency. All factor loadings exceed the critical value of 0.7, with the AVE values surpassing 0.5 and the CR values exceeding 0.7, confirming good convergent validity. As shown in Table 2, all correlation coefficients were below 0.7, indicating the absence of multicollinearity. Furthermore, the square root of the AVE was greater than the corresponding inter-construct correlations, providing evidence of discriminant validity. Therefore, the measurement instrument used in this study has good reliability and validity.

Table 1: Reliability and Convergent Validity

Variable	Cronbach's α	CR	AVE
DFC	0.847	0.847	0.581
DAC	0.841	0.841	0.570
RIC	0.801	0.802	0.574
OI	0.912	0.912	0.564
DIP	0.939	0.939	0.606

Note: CR=composite reliability, AVE=average variance extracted.

The current status of digital innovation capability, open innovation, and digital innovation performance of science and technology-based SMEs in Shanxi, China

As shown in Table 2, the mean values of DFC, DAC, RIC, OI, and DIP were 3.72, 3.77, 3.86, 3.72, and 3.59, respectively, ranging from 3 to 4. Among the three dimensions of digital innovation capability, RIC had the highest mean value of 3.86, followed by DAC with a mean value of 3.77 and DFC with a mean value of 3.72. On the original scale, three indicates “neutral” and four indicates “agree”. Therefore, based on the mean values, the managers are not yet satisfied with the digital innovation capability and open innovation of their firms.

Table 2 Correlations, Discriminant validity, Means, and Standard deviations

Variables	1.	2.	3.	4.	5.	Mean	S.D.
1. DFC	0.762					3.72	1.21
2.DAC	0.528**	0.755				3.77	1.23
3. RIC	0.445**	0.430**	0.758			3.86	1.16
4.OI	0.492**	0.525**	0.425**	0.751		3.72	1.24
5. DIP	0.470**	0.509**	0.433**	0.506**	0.778	3.59	1.30

Note: S.D.=standard deviation, * denotes $p < 0.05$, ** denotes $p < 0.01$; diagonal is the square root of AVE.

Overall model fit

To test the research hypotheses, a path analysis of the structural equation model was conducted based on the overall model (Figure 2). Firstly, the overall model fit was examined, and the results, along with relevant standards, are presented in Table 3. The model fit indices met the recommended critical value, thereby confirming the reasonable validity of the overall model.

Table 3. Model validation

	Statistical Measure Used for Evaluation						
	χ^2/df	GFI	AGFI	CFI	IFI	NFI	RMSEA
Standard criteria	$1 < \chi^2/df < 3$	>0.9	>0.9	>0.9	>0.9	>0.9	<0.08
Test results	1.098	0.937	0.925	0.995	0.995	0.942	0.016

Note: GFI=Goodness of Fit Index, AGFI=Adjusted Goodness of Fit Index, CFI=Comparative Fit Index, IFI=Incremental Fit Index, NFI=Normed Fit Index, RMSEA=Root Mean Square Error of Approximation.

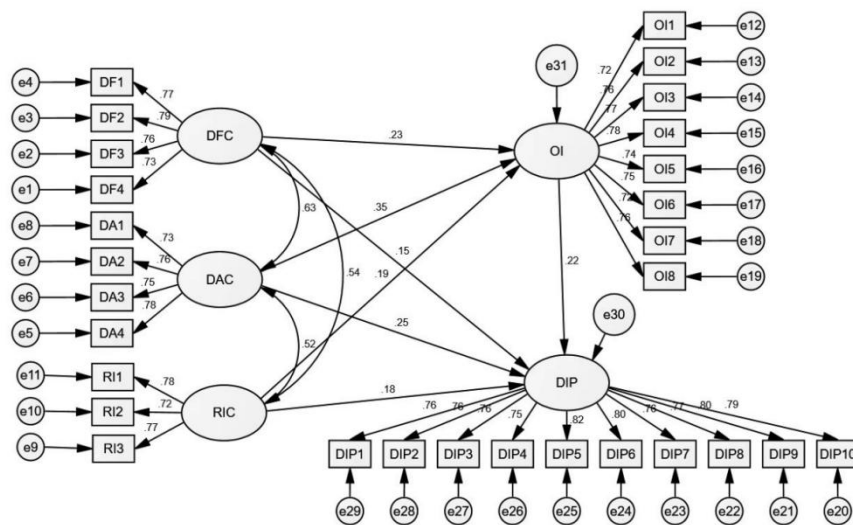


Figure 2: Structural equation model

Hypothesis testing

Direct effects. As shown in Figure 2 and Table 4, the direct effects of DFC on DIP ($\beta=0.15$, $p=0.03$), DAC on DIP ($\beta=0.25$, $p<0.01$), and RIC on DIP ($\beta=0.18$, $p=0.004$) were all significant and positive, thereby supporting hypotheses H1a, H1b, and H1c, respectively. Among them, DAC had a greater impact on DIP than DFC and RIC. The direct effect of DFC on OI ($\beta=0.23$, $p<0.001$), DAC on OI ($\beta=0.35$, $p<0.001$), and RIC on OI ($\beta=0.19$, $p=0.003$) were also significant and positive, supporting hypotheses H2a, H2b, and H2c, respectively. The direct effect of OI on DIP ($\beta = 0.22$, $p < 0.001$) was significant and positive, supporting Hypothesis H3. These results indicate that digital foundational capability, digital agility capability, reorganization innovation capability, and open innovation all have a positive influence on digital innovation performance, providing strong empirical support for further exploring how these factors promote digital innovation performance.

Table 4: Direct effects

Hypothesis	Path	β	S.E.	C.R.	P-value	Results
H1a	DFC→DIP	0.149	0.080	2.174	0.030	Supported
H1b	DAC→DIP	0.247	0.077	3.471	***	Supported
H1c	RIC→DIP	0.182	0.070	2.906	0.004	Supported
H2a	DFC→OI	0.235	0.068	3.336	***	Supported
H2b	DAC→OI	0.352	0.063	4.941	***	Supported
H2c	RIC→OI	0.188	0.059	2.962	0.003	Supported
H3	OI→DIP	0.224	0.075	3.625	***	Supported

Note: *** denotes $p < 0.001$.

Mediation effects. The mediation effects were evaluated using the bootstrap procedure in AMOS 24.0, with a bootstrap confidence interval that excludes zero, indicating a significant indirect effect. (Freedman, 1981). In this study, 2,000 resamples were used to generate bias-corrected and percentile confidence intervals at the 95% confidence level. (Tibbe & Montoya, 2022) (Table 5). Specifically, the indirect effect value of DFC on DIP through OI was 0.053, with a 95% confidence interval of (0.014, 0.126), which excludes zero and thus supports hypothesis H4a. The indirect effect value of DAC on DIP through OI was 0.079, with a 95% confidence interval of (0.025, 0.174), also excluding zero and supporting hypothesis H4b. The indirect effect value of RIC on DIP through OI was 0.042, with a 95% confidence interval of (0.008, 0.108), which excludes zero and supports hypothesis H4c. These results suggest that open innovation serves as a mediator in the relationship between the three dimensions of digital innovation capability and digital innovation performance.

Table 5: Mediation effects test

Hypothesis	Path relationship	Effect value	Bias-Corrected 95% CI	Results
			(Lower, Upper)	
H4a	DFC→OI→DIP	0.053	(0.014,0.126)	Supported
H4b	DAC→OI→DIP	0.079	(0.025,0.174)	Supported
H4c	RIC→OI→DIP	0.042	(0.008,0.108)	Supported

Discussions

First, for research objective 1, the current status of digital innovation capability, open innovation, and digital innovation performance of science and technology-based SMEs in Shanxi Province was assessed using descriptive statistical analysis. The results found that among the three dimensions of digital innovation capability, reorganization innovation capability exhibited the highest mean value of 3.86, followed by digital agility capability with a mean value of 3.77. This pattern is consistent with the developmental needs of science and technology-based SMEs, which are typically characterized by limited resources and smaller organizational scales. Enhancing reorganization and digital agility capabilities can enable these firms to maximize their digital innovation potential within constrained resource environments. For instance, Datang Xinke (Shanxi) Network Technology Co., Ltd. allocates 15% of its operating revenue to research and development (R&D) and possesses several self-developed core technologies, which collectively contribute to its superior digital innovation capability (Chen & Wen, 2022). The mean value of open innovation was found to be 3.59, which is the lowest and is closely associated with the industrial structure of Shanxi Province. The “one-coal-dominant” industrial pattern has constrained the investment and development of SMEs in open innovation. Moreover, Shanxi province is relatively underdeveloped in terms of innovation platforms and carrier construction.

Second, for research objective 2, the impact of digital innovation capability on the digital innovation performance of science and technology-based SMEs was investigated through path analysis. The results indicated that digital foundational capability, digital agility capability, and reorganization innovation capability all exert positive effects on firm digital innovation performance, with path coefficients of 0.15, 0.25, and 0.18, respectively. Among these, digital agility capability has the most significant impact on firm digital innovation performance, followed by reorganization innovation capability and digital foundational capability. This finding may be attributed to the rapidly changing market environment in the digital age. Digital agility capability enables firms to quickly adjust their innovation strategies, helping them to rapidly capture market dynamics and identify new market opportunities earlier, thereby gaining a competitive edge in the digital innovation process. This is consistent with previous studies. Rumanti et al. (2022) employed partial least squares structural equation modeling (PLS-SEM) to empirically examine whether open innovation can significantly contribute to organizational performance in batik SMEs (Rumanti et al., 2022). Kő et al. (2022) explored the positive impact of digital agility on the innovation performance of SMEs (Kő et al., 2022). Similarly, Zhang et al. (2024) noted that SMEs should

enhance their organizational agility to perceive digital technology changes better and integrate digital resources, thereby improving digital transformation (Zhang et al., 2024). By quantifying the dimensions of digital innovation capability, this study not only echoes the aforementioned research but also focuses on science and technology-based SMEs, confirming the positive impact of digital innovation capability on digital innovation performance.

Third, for research objective 3, the mediating role of open innovation in the relationship between digital innovation capability and digital innovation performance was examined using the bootstrap method. The results showed that open innovation played a mediating role in the relationship between the three dimensions of digital innovation capability and digital innovation performance, with effect values of 0.053, 0.079, and 0.042, respectively. Among these, digital agility capability exhibited the most substantial mediating effect. This indicates that a higher level of digital agility capability is more conducive to the implementation of open innovation within firms. In turn, open innovation significantly contributes to enhancing digital innovation performance. These findings are consistent with previous studies. Wang et al. (2023) utilized data from 347 firms to show that digital platform capabilities can positively influence sustainability-oriented innovation through open innovation mechanisms (Wang et al., 2023). From a resource integration perspective, Wu et al. (2022) conducted a multi-case analysis of four different types of manufacturing firms, elucidating that firms can enhance their open innovation capabilities by promoting the identification and access to digital resources, resource matching, and utilization through digital capabilities (Wu et al., 2022). Considering the inherently boundaryless nature of digital technologies, this study constructs a theoretical model of digital innovation capability, open innovation, and digital innovation performance, contributing to both echoing and extending previous studies.

Conclusion

Adhering to the logical evolution process of “capability–behavior–performance” and focusing on science and technology-based SMEs in Shanxi, China, this study assessed not only the status of digital innovation capability, open innovation, and digital innovation performance but also explored the relationships among them using a quantitative, cross-sectional SEM approach. The findings hold both theoretical and practical significance.

First, digital innovation capability, open innovation, and digital innovation performance of science and technology-based SMEs in Shanxi Province were not yet at a satisfactory level. This indicates that science and technology-based SMEs have made a certain degree of progress in enhancing their digital innovation capabilities, open innovation practices, and digital innovation performance, with a particular emphasis on cultivating reorganization innovation capabilities. However, the levels of open innovation and digital innovation performance remain relatively low, indicating substantial potential for future development.

Second, digital foundational capability, digital agility capability, and reorganization innovation capability all positively influence digital innovation performance, with digital agility capability emerging as the most significant driver. Despite the critical importance of digital innovation capability for firm development, existing research in this area is still nascent, with limited discussion on the dimensions and impacts of digital innovation capability. These findings not only enrich theoretical research on digital innovation capability and digital innovation performance but also expand the research on RBV and DCT within the context of the digital economy. In the context of global digital transformation, science and technology-based SMEs should actively build corresponding digital agility capabilities to break free from the constraints of their development.

Third, open innovation significantly mediates the relationships between the three dimensions of digital innovation capability and digital innovation performance, with varying effects across capability dimensions. This not only refines open innovation theory, but also enriches the research on the path mechanisms through which digital innovation capability affects digital innovation performance. Although the strong connectivity of digital technologies has greatly enriched the resources of firms, open innovation continues to have a positive impact on the relationship between digital innovation capability and digital innovation performance. Therefore, this study provides a basis for science and technology-based SMEs to improve their digital innovation performance through active open innovation.

Suggestions

Suggestions for firms and policymakers

First, enhance reorganization innovation capability. Firms should implement flexible mechanisms, such as “dual appointments” for scientific researchers between institutions and firms, to specifically target the cultivation and recruitment of digital talent with innovative capabilities and

practical experience. Establishing a data management platform can provide a continuous supply of innovative resources for firm reorganization innovation. The government can support firms by reducing the burden of reorganization innovation through preferential tax policies. At the same time, financial institutions can offer diversified financing channels, such as intellectual property pledge loans and technology insurance, to facilitate innovation in reorganization.

Second, emphasize the role of digital agility capability. Firms should leverage computing technology to rapidly and accurately capture customer behaviour and market trends. Additionally, providing training in digital agility skills and professional digital tools can enhance employees' digital agility capabilities. Encouraging employees to explore digital knowledge independently can further foster a culture of agility within the organization.

Third, engage in open innovation. As digital technologies increasingly blur the boundaries of traditional industries, open innovation has become a vital strategy for maintaining competitiveness. Through industry–university–research (IUR) cooperation, firms can obtain key digital technology support and promote the transfer and application of advanced technologies and knowledge. Establishing a supply chain visualization platform can help firms build stable multilateral cooperative relationships, thereby enhancing the overall synergy and efficiency of supply chain operations. Furthermore, government–led innovation alliances can encourage high-tech firms to actively integrate into regional innovation networks, thereby improving the efficiency of knowledge flow among innovation stakeholders.

Suggestions for future research

This study utilized cross-sectional data, which captured the characteristics of the variables at a single point in time, and the questionnaire data were subjectively biased. Future studies might adopt longitudinal designs to capture the dynamic evolution of digital innovation capability over time, thereby enhancing the accuracy and robustness of the research results. Additionally, this study focused solely on science and technology-based SMEs in Shanxi Province, China, and the findings may not be generalizable to other countries, regions, or firms of different natures. Future research could employ comparative case studies across industries or provinces to enhance the generalizability of the research conclusions. The inclusion of moderating variables, such as leadership style or digital maturity level, could further enrich the analysis of these relationships and provide deeper insights into the factors influencing digital innovation performance.

New Knowledge

This study begins by taking digital innovation capability as its starting point. It employs DCT to categorize digital innovation capability into three distinct dimensions: digital foundational capability, digital agility capability, and reorganization innovation capability. This not only expands the dynamic capability framework but also refines the current classification of digital innovation capability dimensions. It provides a more nuanced understanding of the specific digital innovation capabilities that science and technology-based SMEs need to build and offers valuable guidance for relevant government departments in formulating targeted digital innovation policies.

This study introduces open innovation as a mediating variable and constructs a theoretical model linking “digital innovation capability–open innovation–digital innovation performance”. This model aligns with the established research paradigm of “firm capability–competitive advantages–firm performance”, and offers a new perspective on the dynamic process of digital transformation in science and technology-based SMEs. It underscores the importance of open innovation in enhancing digital innovation performance. It suggests that firms should prioritize the development of digital innovation capabilities while leveraging open innovation models to accelerate their digital innovation processes. At the same time, policymakers should establish an open innovation platform by introducing policies such as tax incentives and financial subsidies, thereby promoting the development of regional digital innovation ecosystems.

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