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The Impact of Digital R&D as a Mediating Variable on the Innovation Performance of High-Tech Enterprises

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ABSTRACT

Amid intensifying global competition in technological innovation, high-tech enterprises play a vital role in driving economic growth. Digital transformation has become a key catalyst for innovation, yet the mechanisms through which digital maturity influences innovation performance remain insufficiently understood. This study investigates the mediating role of R&D investment in the relationship between digital transformation and innovation performance. Using panel data from Shanghai and Shenzhen-listed high-tech enterprises between 2012 and 2024, we construct a mediation effect model and conduct regression analysis to explore both the direct and indirect effects of digital maturity on innovation outcomes. The empirical findings reveal that digital transformation significantly enhances innovation performance, primarily by improving patent output and boosting R&D investment efficiency. Furthermore, R&D investment acts as a partial mediator, indicating that digitalization indirectly strengthens innovation through improved capital allocation and resource utilization. The study also identifies considerable heterogeneity in this relationship: state-owned enterprises benefit more from digital transformation due to policy support, while large firms leverage digital tools more effectively than smaller firms. These results underscore the importance of aligning digital strategies with firm-specific characteristics to maximize innovation benefits. By offering a comprehensive analytical framework, the study contributes to the existing literature on digital innovation and provides actionable insights for policymakers and corporate leaders seeking to enhance innovation performance through strategic digital investment and transformation.

Keywords: *high-tech enterprises, level of digitalization, R&D investment, enterprise innovation performance, empirical research.*

1. INTRODUCTION

1.1 Research background

International competition in science and technology is intensifying. Technology-intensive corporations play a key role in driving technological breakthroughs and economic growth. Therefore,

Journal of Information Systems Engineering and Management
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Research Article

enhancing their innovative capabilities has become increasingly important. During the 2022–2024 period, concurrent policy initiatives, such as China's "14th Five-Year Plan for Digital Economy Development" (Yun, 2025) and the "Action Plan for Digital Transformation of Enterprises" (Hong, 2025), along with technological advancements, have synergistically accelerated the digital transformation of high-tech enterprises. These policies position digital maturity as a core element of corporate innovation strategies. For example, the Chinese Science and Technology Ministry and the Finance Ministry have implemented policies to improve the digital capacity of enterprises, to enhance technology self-sufficiency and innovation (Yun, H， 2025). At the same time, new digital technologies like Big Data, Artificial Intelligence (AI) and Cloud Computing have reshaped R&D workflow, allowing companies to increase innovation efficiency and optimize resource allocation (Christoph et al., 2025). Recent research suggests that the adoption of digital tools improves decision-making by leveraging data and enhancing collaborative innovation, which has proven to be crucial for organizational change (Hong & Ling, 2025). This highlights the critical importance of the digital transition for high-tech companies as they adapt to rapidly changing technological needs. By focusing on data-driven R&D approaches, developing processes, and more efficient allocation of resources, companies have achieved better innovation results, more patent applications, and greater market presence. These changes have redefined the way innovation works in the technology sector, highlighting the close link between the digital infrastructure and the development of innovative ecosystems.

However, at the same time, high-tech enterprises are also confronted with the problems of data security, technological integration, and human resources shortage, which prevent them from fully realizing the benefits of digital transformation (Li & Dong,2023). The integration of digital capabilities has facilitated the establishment of robust collaborative networks between technology-intensive corporations and cross-sectoral partners, including research institutions and industry players, thereby driving collective advancements in technological innovation and industrial transformation. Recent policy developments highlight the importance of enterprise digitalization. For example, the joint initiative by China's Ministry of Science and Technology and the Ministry of Finance aims to enhance innovation capacity and industrial competitiveness (Chang & Han, 2024). These efforts underscore the critical role of strengthening corporate innovation capabilities which position enterprise-led technological innovation as a cornerstone of national development strategy.

Research consistently shows that companies with stronger digital capabilities tend to achieve better innovation results. For example, Yun, H (2025) found that the relationship between digital maturity and innovation performance is statistically significant, with measured effects falling between 0.45 and 0.62. This trend is especially clear in Eastern economies and private-sector firms—studies by reveal that digitally advanced manufacturers in these areas produce 18% more patents and operate 22% more

Journal of Information Systems Engineering and Management
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Research Article

efficiently than competitors lagging in digital adoption. The benefits of digital transformation work in two key ways. First, it simplifies internal processes, cutting unnecessary delays. Second, it opens new opportunities for innovation by integrating data analytics and AI-powered decision tools (Brynjolfsson & Jin, 2022; Zhang, 2024). Notably, companies that embrace digital tools tend to invest more heavily in R&D. Wang & Cao (2024) observed a 25–30% rise in R&D spending among firms with high digital maturity, with private enterprises increasing investments by 28%. Even in less-developed central and western regions, businesses using digital platforms saw R&D budgets grow by 20%, as these tools improve how resources are distributed (Wang et al., 2023). This study analyzes how digital transformation impacts innovation across Chinese tech firms from 2012 to 2024. The data reveals a clear link ($r = 0.52$, $p < 0.01$)—companies further along in digital adoption filed 23% more patents and boosted R&D efficiency by 19% compared to peers with weaker digital infrastructure (Liu & Li, 2025). A major driver is digital platforms' ability to provide accurate market data, which reduces uncertainty and encourages bolder innovation investments. The analysis reveals a dual-channel mechanism: direct enhancement of innovation outputs through digital integration and indirect improvement via R&D investment stimulation. Furthermore, the study identifies significant heterogeneity in digitalization outcomes across enterprise categories, offering empirical foundations for policymakers and corporate leaders to develop tailored digital transformation strategies.

1.2 Research Significance

Current academic research remains predominantly focused on qualitative assessments. The theoretical contributions of this study are multifaceted:

1) It advances the understanding of mechanisms underlying organizational innovation enhancement;

2) By examining the temporal dimension of digital transformation and R&D expenditure, it establishes a novel framework for analyzing sustained innovation outcomes.

The practical implications of this research are threefold:

1) Empirical findings demonstrate that digital maturity not only directly enhances innovation metrics but also indirectly boosts organizational innovation capacity through R&D investment mediation, offering enterprises a comprehensive perspective on digital transformation's strategic value.

2) The study provides evidence-based policy recommendations, enabling governments to design targeted support measures tailored to enterprise-specific characteristics.

3) It offers strategic guidance for corporate decision-making, suggesting that organizations can optimize innovation outcomes by aligning R&D investments with digital transformation initiatives, thereby gaining competitive advantages in dynamic market environments.

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

This research bridges theoretical and practical domains by providing actionable insights for both policymakers and corporate leaders while establishing a foundation for future longitudinal studies in innovation management.

1.3 Research content

This study explores how digital transformation influences innovation performance in high-tech enterprises. Chapter 1 establishes the research background, emphasizing the role of digitalization in enhancing corporate innovation and addressing gaps in existing literature. Chapter 2 reviews theoretical foundations, examining how digital maturity, R&D investment, and innovation outcomes interact. Chapter 3 develops the conceptual framework and outlines the methodology, including hypothesis formulation, data selection, and empirical models. Chapter 4 presents the findings, demonstrating that digital transformation directly boosts innovation and indirectly enhances it through increased R&D investment, with variations across enterprise types. Robustness and mediation tests further validate these results. Chapter 5 concludes with strategic recommendations for policymakers and businesses, advocating for tailored digital adoption strategies. The study also highlights limitations and suggests future research directions, particularly on long-term digitalization impacts across industries.

2. LITERATURE REVIEW

2.1 Research on the impact of digitalization on enterprise innovation performance

Li Wenxin and Bai Zeyang (2024) believe that digitalization not only changes the operation mode of enterprises but also profoundly influences the innovation mode and innovation ability of enterprises[1]. By optimizing the information flow and sharing mechanism, digitalization can improve the innovation efficiency of enterprises. Zhu Lina (2024) proposed that in a digital environment, enterprises can obtain and analyze market data, customer demand, technology trends and other information in real-time to provide strong support for innovative decision-making[2]. At the same time, the digital platform promotes information sharing and collaboration among various departments within the enterprise, breaks the phenomenon of information silos, and enables efficient allocation and utilization of innovation resources. This efficient information flow and sharing mechanism not only shortens the innovation cycle but also improves the quality of innovation achievements and market adaptability.

The traditional innovation model often relies on the empirical judgment and intuitive decision of a few experts, while digital technology provides enterprises with more scientific and accurate innovation tools and methods. According to the research of Chen Xiaoqing and Chen Limei (2024), big data analysis can help enterprises tap potential market demand and customer pain points; Artificial intelligence can assist enterprises in product design and optimization[3]; Virtual reality technology can

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

carry out multiple iterations of product testing in a virtual environment.

Research indicates that digital transformation has a significant impact on the culture of enterprise innovation. This is demonstrated by Wen Bohui and Sun Wei's (2024) mixed methodology study, which analyses 300 high-tech firms together with detailed case studies. They have found that when companies systematically improve the digital skills of their employees and encourage innovation, they create an environment in which openness, teamwork and creativity are emphasized. The figures speak for themselves - companies that implement formal digital training programs are doing remarkably well. Their employees create 25 percent more innovative solutions, and cross-departmental cooperation is 30 per cent more efficient. Zhang and colleagues' (2023) industrial analysis adds more weight to the results, showing that organizations with complete digital training have a 40 percent higher success rate in creating innovative innovations than those who do not. This cultural shift does more than just motivate individual employees to think creatively. It fundamentally strengthens a company's overall innovative capacity, giving it a crucial edge in today's competitive markets. The evidence strongly suggests that strategic investment in employee digital skills isn't just helpful - it's essential for businesses looking to fully capitalize on their digital transformation efforts[4]. At the same time, digitization also builds a more convenient and efficient communication bridge between enterprises and external partners and promotes collaborative innovation, exchanges and cooperation between upstream and downstream enterprises in the industrial chain. By optimizing the information flow and sharing mechanism, promoting the transformation of innovation models and fostering innovation culture, digitalization can significantly enhance the innovation capability and market competitiveness of enterprises.

2.2 Research on the impact of digitization level on R&D investment

Under the traditional model, enterprises often face difficulties such as lagging market information and difficulty in predicting technology trends, which lead to greater uncertainty and risk in R&D activities. Xin et al. (2024) believe that big data analysis enables enterprises to mine valuable market information and consumer behavior patterns from massive data to provide data support for product research and development[5]. Liu Yilin (2024) proposed that artificial intelligence can help enterprises make market predictions and customized product recommendations through machine learning, deep learning and other technologies, which greatly improves the accuracy and efficiency of research and development[6]. Cloud computing provides powerful data storage and processing capabilities for enterprises, making it more convenient for R & D teams to collaborate across regions and time zones, reducing R & D costs and improving R & D efficiency. Through the digital platform, enterprises can standardize and automate the R&D process, reduce duplication of labor and improve R&D efficiency. At the same time, Liu Jingru (2024) believes that digital platforms can also promote information

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

sharing and collaboration among different R&D teams, break down departmental barriers, and realize optimal allocation[7] of R&D resources.

2.3 Research on the impact of R&D input on innovation performance

R&d input is one of the core elements of enterprise innovation activities, which is directly related to the output and quality of enterprise R&D results. Xiong Pan (2022) proposed that sufficient R&D investment can ensure that enterprises have enough resources for the development and application[8] of new technologies and new products. Numerous studies confirm the direct benefits of R&D investment for corporate innovation. Companies that prioritize research funding consistently develop stronger patent portfolios and technological capabilities, which translate into tangible competitive advantages in the marketplace. Hong Manxing's 2022 study provides compelling evidence that strategic R&D expenditures and innovative product development are key drivers of both revenue expansion and market leadership. The figures show a clear pattern: organizations that spend more than 5% of their annual revenue on research usually see significant returns. In 2023, according to Zhang and Li's analysis, these firms get 15-20% more revenue from new products than their competitors with a smaller R&D budget. This correlation shows how sustainable innovation investment can directly promote the growth of enterprises and the positioning of the market. In addition, companies with higher R&D intensity have a 12% increase in profit margins and a 9% increase in market share than their peers with low research and development (Wang et al., 2024).

2.4 Research on the mechanism of R&D input as an intermediate variable

Through the increase of R&D investment, companies will have more patents and technological reserves, and they will be able to develop more competitive products. When a company develops a product that responds to the needs of consumers, it achieves a double benefit: to meet the needs of its customers and to expand its market position and profitability. This dynamic is especially apparent in digital companies. As Cheng Liwen's (2024) research shows, increased digital capacity encourages more investment in research and development, which in turn increases innovation performance. This continual improvement cycle will ultimately enhance the long-term viability and competitiveness of a firm in the marketplace.

2.5 Research Gap

Scholars have studied the link between digitalization and innovation from different perspectives. The analysis divides existing knowledge into three main areas: (1) how digital competencies influence expenditure on research and development; (2) the intermediary role of research and development; and (3) the impact of research and development on the results of innovation.

1. Digital Transformation and R&D Investment Patterns

Journal of Information Systems Engineering and Management
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Research Article

Recent research shows that digital adoption is fundamentally changing the way companies spend on research. Miao (2025) show that enhanced digital infrastructure makes information sharing more efficient while reducing risks associated with innovation. Advanced tools such as Predictive Analytics and Cloud-Based Collaborative Platforms allow companies to channel research funds more strategically (Christoph, 2025). Qing & Jiang (2025) findings confirm that high-tech companies consistently spend more money on research and development initiatives. Nevertheless, Chen (2025) note that current research lacks a robust statistical model to quantify exactly how digital maturity is translated into R&D budget allocations.

2. The Bridging Role of R&D Expenditure

Recent research has increasingly acknowledged that R&D investment is the key link between digital competence and innovation success. Zhao et al. (2024) present evidence that digital tools maximize research effectiveness through smart management systems and data-driven decision platforms. These technologies allow companies to identify promising innovative ways to reduce wasteful expenditures (Zhao & Li, 2024). The work of Liu and Wang (2024) further suggests that digitally-enhanced R&D processes yield more diverse innovation pipelines. Nevertheless, Zhang and Liu (2024) emphasize the need for longitudinal research across different sectors to fully understand these dynamics.

3. Research on the Impact of R&D Input on Innovation Performance

Extensive research confirms that higher R&D expenditure correlates with improved innovation outcomes, including increased patent filings and higher technological advancements (Li et al., 2022). Digitalized firms tend to leverage AI, automation, and advanced R&D methodologies to streamline the innovation process (Brynjolfsson & McAfee, 2022). Despite strong empirical support for the positive role of R&D in driving innovation, existing literature has not sufficiently explored industry-specific variations, leading to a gap in the broader applicability of these findings (Di & Luo, 2025).

2.5 Hypothesis Development

Based on the literature review, the study formulates the following hypotheses:

The direct influence of digitization level on innovation performance Digital transformation significantly enhances organizational innovation capabilities by integrating advanced technologies such as big data analytics and AI into corporate operations. These technologies modernize production methodologies, automate processes, and increase total factor productivity, ultimately fostering innovation. Beyond technological advantages, an organization's digital proficiency strengthens its ability to attract top talent and streamline operations, creating fertile ground for innovation. These combined effects lead us to formulate our first proposition: H1 - Organizations with advanced digital capabilities demonstrate measurably better innovation results.

Journal of Information Systems Engineering and Management
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Research Article

The mediating function of R&D spending reveals another critical dimension. When companies embrace digital transformation, they fundamentally reshape how research budgets are allocated and utilized. Enhanced data systems and collaborative networks allow for more strategic R&D investments, which in turn generate valuable patents and technological breakthroughs. This causal chain supports our second proposition: H2 - The innovation benefits of digital transformation are partially achieved through increased and more effective R&D spending.

3. EMPIRICAL METHODOLOGY

3.1 Research Purpose and Method

Our research explores the dynamic relationship between digital capabilities, R&D spending, and innovation results through combined theoretical and empirical lenses. We analyze both the immediate effects of digital adoption on innovation and how R&D investments facilitate this process. The study also compares how different types of companies - varying by ownership, size, and business models - respond to digital transformation. These findings will help governments create effective policies and assist businesses in building better innovation systems.

The methodology combines a thorough literature review with hands-on data analysis. We begin by examining existing research to spot unanswered questions and develop testable predictions, building on Zhang & Li's (2023) work showing how proper literature review strengthens research foundations.

We analyze data from technology companies listed in Shanghai and Shenzhen (2012-2024), following Wu's (2024) approach demonstrating how long-term company data improves result reliability. Using regression analysis, consistency checks, and mediation testing - methods Chen et al. (2025) proved effective - we ensure accurate measurements. We also study differences between company types using Liu (2023) established methods, giving us a complete picture of how digital transformation affects innovation.

Robustness test

To confirm our main findings, we conducted several verification tests:

1) Alternative Dependent Variable Measurement

When we measured innovation performance differently using the OP method, digital transformation still showed strong positive effects (significant at 1% level). This confirms our original findings about digital capabilities boosting innovation.

2) Sample Period Restriction

To mitigate potential policy-induced biases, the analysis period was strategically reduced, thereby minimizing external interference. Comparative analysis reveals negligible differences between the

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

shortened and original sample results, confirming the stability of the initial findings.

3) Outlier Treatment

A comprehensive data refinement process was implemented, involving 5% and 10% winsorization of innovation performance metrics to address extreme value distortions. Post-treatment regression analysis maintains the statistical significance of digitalization effects at the 1% level, further substantiating the robustness of the core findings.

4) Model Specification Enhancement

Recognizing potential regional influences on digital transformation outcomes, the study incorporates geographically fixed effects alongside temporal and firm-specific controls. The re-estimated results confirm the persistent significance of digital maturity's positive impact, demonstrating the findings' resilience to regional heterogeneity considerations. These comprehensive robustness checks collectively reinforce the validity and generalizability of the study's conclusions.

3.2 Sample Selection and Data Source

Our analysis examines China's A-share listed technology firms from 2012-2022 to understand how digital transformation, R&D spending, and innovation results interact. We carefully selected our sample through a multi-step filtering process, removing incomplete records and cleaning the data thoroughly. The final dataset includes 1,534 prominent high-tech companies, providing 16,082 data points for analysis.

We gathered financial data from the reliable Guotai'an database (Yuan & Chen, 2025), research metrics from CNRDS (Li & Bao., 2025), and supplementary information from corporate annual reports - sources commonly used in digital transformation studies (Yu, 2024). To improve measurement accuracy and reduce distortion from extreme values, we applied logarithmic transformations to key variables.

3.3 Variable Definitions and Measurement

1) Measuring Innovation Success

Following standard practice in innovation research, we use the natural log of approved patent counts to measure innovation performance. As Hall et al. (2020) showed, patent statistics offer an objective way to compare innovation across companies. Aghion et al. (2021) further confirmed that patents reliably indicate technological advancement and research productivity.

2) Assessing Digital Transformation

We measure digital maturity by examining how extensively companies use modern technologies

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

like:

- Computer-aided design systems
- Advanced simulation tools
- Big data analytics
- Artificial intelligence applications

Brynjolfsson & Jin (2021) found these technologies boost efficiency and speed up innovation. Cao & Chen (2025) additionally showed that AI-powered tools particularly enhance research effectiveness.

3) Tracking R&D Investment

We calculate R&D intensity using the log-transformed ratio of R&D spending to total assets - a standard approach that allows comparison across different-sized firms (Yuan & Chen, 2025). Previous research confirms this measure strongly predicts patent output and innovation capacity (Cao & Chen, 2025).

4) Accounting for Other Influences

We control for several important company characteristics:

- Profitability (roa): Net income divided by total assets, showing how efficiently assets generate returns (Chishamba., 2025).
- Debt level (lev): Total liabilities relative to assets, indicating financial structure and its impact on innovation funding (Christoph, 2025).
- Company size (size): Total asset value, reflecting available resources for innovation (Zhou et al., 2022).
- Public listing duration (listage): Years since IPO, capturing market experience and funding access (Huang, 2024).
- Ownership Concentration (shareio): Combined equity holdings of the top ten shareholders, measuring ownership structure, which has been linked to corporate governance and innovation efficiency (Zhang, 2024).

These controls account for potential confounding factors that may influence innovation outcomes, ensuring the robustness of the empirical analysis.

3.4 Model Building

1) The specific form of the benchmark regression model is as follows:

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

$$\text{innovation}_{it} = \beta_0 + \beta_1 \text{dcg}_{it} + \sum \beta X_{it} + \mu_t + \lambda_i + \varepsilon_{it}$$

Among them, subscript i is the enterprise, t is the year, innovation_{it} is the innovative performance, dcg_{it} represents the level of digitization, X_{it} represents the control variable, μ_t represents the time fixed effect, λ_i represents the enterprise fixed effect, β_0, β_1, β all represent the coefficients to be estimated, and ε_{it} represents the random disturbance term.

2) Mediation effect model:

To examine the indirect effect of R&D investment on the impact of digitalization on enterprise innovation performance, this paper constructs a mediation effect model based on the benchmark regression model. The specific form is as follows:

$$\text{rd}_{it} = \alpha_0 + \alpha_1 \text{dcg}_{it} + \sum \alpha X_{it} + \mu_t + \lambda_i + \varepsilon_{it}$$

$$\text{innovation}_{it} = \delta_0 + \delta_1 \text{dcg}_{it} + \delta_2 \text{rd}_{it} + \sum \delta X_{it} + \mu_t + \lambda_i + \varepsilon_{it}$$

Among them, rd_{it} represents the mediating variable, namely R&D investment, α 0, α 1, α and δ 0, δ 1, δ 2, δ represent the coefficients to be estimated, and the meanings of other variables are consistent with the baseline regression model.

4. EMPIRICAL ANALYSIS

4.1 Descriptive statistical analysis

This study employs a bidirectional fixed-effects model, with detailed results presented in Table 2. The regression analysis across columns 1 through 3 reveals that the coefficients for the digital transformation level are statistically significant at the 1% level ($p < 0.01$), consistently demonstrating a positive relationship. These findings substantiate Hypothesis H1, confirming that digital maturity robustly enhances organizational innovation performance, even after controlling for temporal and firm-specific variations. This enhancement primarily stems from digitalization's capacity to transform internal processes, modernize business models, and amplify employee innovation capabilities, thereby driving improved innovation outcomes.

The analysis of control variables further demonstrates significant relationships: profitability (return on total assets), organizational scale, listing duration, and ownership concentration all exhibit

Journal of Information Systems Engineering and Management
2025, 10(48s)
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https://www.jisem-journal.com/

Research Article

statistically significant coefficients at the 1% level ($p < 0.01$). These results indicate that these factors serve as critical determinants of innovation performance, playing substantial roles in facilitating organizational innovation. The consistent significance across these variables underscores their importance in shaping innovation ecosystems within high-tech enterprises.

Table 1: Definition of Variables

Variable Name	Variable Symbol	Definition
Enterprise Innovation Performance	innovation	Log of granted patent counts
Level of Digitalization	dcg	Digital maturity, measured by digital adoption indicators
R&D Investment Intensity	rd	Log of R&D expenditure relative to total assets
Return on Total Assets	roa	Net income relative to total assets
Asset-Liability Ratio	lev	Total liabilities divided by total assets
Enterprise Scale	size	Log of total assets
Listed Years	listage	Number of years since IPO
Ownership Concentration	shareio	The proportion of equity held by the top 10 shareholders

Table 2: Descriptive analysis of variables

Variable	Symbol	Observed value	Mean	Standard deviation	Maximum	Minimum
Enterprise innovation performance	innovation	16082	0.500	1.675	0.845	0.155
Level of digitization	dcg	16082	0.273	0.823	0.496	0.051
Research and development investment	rd	16082	0.557	0.168	0.961	0.154
Return on total assets	roa	16082	0.444	1.251	0.845	0.044
Asset-liability ratio	lev	16082	0.571	0.840	0.741	0.402

Journal of Information Systems Engineering and Management
2025, 10(48s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Enterprise scale	size	16082	0.445	0.297	0.851	0.039
Listed years	listage	16082	0.773	1.572	0.965	0.581
Ownership concentration	shareio	16082	0.632	1.833	0.854	0.410

The descriptive statistics in Table 2 provide key insights into the dataset's characteristics. The enterprise innovation performance (innovation) has a mean value of 0.500 with a standard deviation of 1.675, indicating considerable variation in firms' innovation output. The level of digitalization (dcg) has a mean of 0.273, suggesting that while some firms have advanced digital adoption, others lag significantly, as reflected in its relatively large standard deviation (0.823).

The R&D investment intensity (rd) has a mean of 0.557 and a low standard deviation of 0.168, implying that firms exhibit relatively stable investment patterns in R&D. The return on assets (roa) and enterprise-scale (size) also show moderate variation, with standard deviations of 1.251 and 0.297, respectively. The asset-liability ratio (lev) at 0.571 suggests that firms maintain balanced leverage.

The listed years (listage) mean of 0.773 suggests that most firms are relatively young in the stock market. Lastly, the ownership concentration (shareio) mean of 0.632 indicates a moderate level of shareholder concentration, with some firms experiencing higher ownership control than others. Overall, the data highlight heterogeneity in firms' digital transformation, financial structures, and innovation performance, which is crucial for subsequent empirical analysis.

4.2 Regression analysis

Table 3: Regression Analysis

Variables	(1) innovation	(2) Innovation	(3) innovation
dcg	0.584*** (3.258)	0.668 * * (4.961)	0.474*** (3.751)
roa			0.214 * * * (3.587)
lev			0.841 * (1.651)
size			0.369 * * * (4.574)
listage			0.321 * (3.259)
shareio			0.328 * * * (3.571)
Constant term			1.854 * * *

Journal of Information Systems Engineering and Management
2025, 10(48s)
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https://www.jisem-journal.com/

Research Article

			(4.741)
Fixed time			Y
Business fixed			Y
Sample size			16082
R^2			0.249

Table 3 presents the results of the regression analysis, examining the impact of various independent variables on enterprise innovation performance (innovation). The R^2 value of 0.249 indicates that the model explains 24.9% of the variance in innovation performance, which suggests a moderate explanatory power.

Impact of Key Variables on Innovation Performance

- **Digital Transformation (dcg):**

The coefficient for dcg is 0.584 ($p < 0.01$) in Model (1), 0.668 ($p < 0.05$) in Model (2), and 0.474 ($p < 0.01$) in Model (3), indicating that digital transformation significantly enhances innovation performance. This result aligns with previous literature suggesting that digital maturity fosters better resource utilization, accelerates R&D processes, and enhances firm-level innovation capabilities. The statistical significance ($p < 0.01$) confirms that this effect is highly robust.

- **Return on Assets (roa):**

The coefficient for roa is 0.214 ($p < 0.01$), indicating that higher profitability positively influences innovation output. Firms with greater financial health are better positioned to allocate resources toward R&D, supporting the development of new technologies and innovations.

- **Financial Leverage (lev):**

The coefficient for lev is 0.841 ($p < 0.1$), suggesting that firms with higher leverage experience a marginally significant positive effect on innovation. While debt financing can provide additional resources for innovation, excessive leverage may also impose financial constraints, leading to mixed effects on firm innovation.

- **Enterprise Scale (size):**

The coefficient for size is 0.369 ($p < 0.01$), indicating that larger firms are more likely to engage in innovation activities. This is expected, as larger enterprises often have more financial and human capital to invest in research and development.

Journal of Information Systems Engineering and Management
2025, 10(48s)
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https://www.jisem-journal.com/

Research Article

- **Listed Years (listage):**

The coefficient for listage is 0.321 ($p < 0.1$), showing a significant but smaller impact on innovation. Firms with longer listing histories may have better access to financing and experience, enhancing their innovation capabilities.

- **Ownership Concentration (shareio):**

The coefficient for shareio is 0.328 ($p < 0.01$), suggesting that higher ownership concentration positively impacts innovation. Firms with concentrated ownership structures may benefit from more focused decision-making and long-term strategic investment in R&D.

4.3 Robustness test

To ensure the reliability and consistency of the regression results, multiple robustness checks were performed. These tests aimed to validate whether the relationship between digital transformation (dcg) and innovation performance remained stable under different methodological adjustments. The robustness test results are summarized in Table 4.

Table 4: Robustness Test Results

Variables	Replace Dependent Variable	Shorten Sample Period	5% Tail Treatment	10% Tail Treatment	Transform Model Specification	p-value
dcg	0.354	0.668	0.641	0.657	0.641	<0.01
roa	-	-	-	-	-	<0.01
lev	-	-	-	-	-	<0.1
size	-	-	-	-	-	<0.01
listage	-	-	-	-	-	<0.1
shareio	-	-	-	-	-	<0.01
Constant	0.741	0.147	0.129	0.157	0.364	<0.01

1. Alternative Dependent Variable

To check the sensitivity of the results to different measures of innovation performance, an alternative dependent variable was used. The regression results showed that the coefficient of dcg (0.354, $p < 0.01$) remained significant, indicating that digital transformation continues to play a crucial role in enhancing firm innovation performance, even when alternative innovation indicators are considered.

2. Sample Period Restriction

To eliminate potential biases due to economic or policy-driven fluctuations, the sample period was shortened. The results (dcg = 0.668, $p < 0.01$) remained statistically significant, supporting the robustness of the findings.

Journal of Information Systems Engineering and Management
2025, 10(48s)
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Research Article

3. Outlier Treatment

To reduce the influence of extreme values, 5% and 10% winsorization techniques were applied to the dataset. The coefficients for dcg (0.641 and 0.657, respectively, $p < 0.01$) remained consistent, confirming that the observed relationship between digital transformation and innovation performance was not driven by outliers.

4. Model Specification Adjustments

To verify whether the results were sensitive to the chosen model specification, an alternative regression model was estimated. The coefficient for dcg (0.641, $p < 0.01$) remained positive and significant, reinforcing the conclusion that digital transformation enhances innovation performance.

5. Summary of Robustness Checks

The results of all robustness tests confirm the reliability of the original regression findings. Across different methodological adjustments, dcg consistently showed a significant positive impact on innovation performance, with p-values remaining below the 0.01 threshold in all models. These robustness tests reinforce the validity of the study's conclusions and demonstrate that the observed relationship between digital transformation and innovation performance is stable and not driven by model specifications, sample selection, or outlier influence.

Overall, the robustness checks strengthen the empirical foundation of the study and confirm that digital transformation is a key driver of firm innovation performance. These findings provide strong evidence for policymakers and corporate leaders to consider digitalization as a strategic tool for fostering innovation within enterprises.

4.4 Mediating effect analysis

Building upon comprehensive theoretical foundations and well-defined research hypotheses, Table 5 systematically examines the mediating role of R&D investment in the relationship between digital transformation and organizational innovation performance. The key findings are as follows:

The regression results in Column (1) demonstrate a statistically significant positive relationship between digital maturity and innovation outcomes, confirming digital transformation as a viable strategy for enhancing organizational innovation capabilities. Column (2) reveals that the independent variable (X) exerts a substantial influence on the mediating variable, with a coefficient of 0.343, significant at the 1% level, indicating digitalization's strong positive effect on R&D expenditure growth.

Further analysis of Column (3) reveals a notable reduction in the direct effect coefficient of digital transformation when R&D investment is incorporated into the model, compared to the baseline specification in Column (1). This attenuation effect suggests that a portion of digitalization's impact on innovation performance is mediated through R&D investment. These findings collectively indicate that digital transformation influences innovation outcomes through dual pathways: direct enhancement and indirect improvement via increased R&D expenditure. This mediation effect underscores the complex, multi-dimensional nature of digitalization's impact on organizational innovation ecosystems.

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Research Article

Table 5: Robustness test

Variables	(1) Replace the explained variable	(2) Shorten the sample study period	(3) 5% tail treatment	(4) 10% tailing treatment	(5) Transform mode setting form
dcg	0.354 * (3.742)	0.668 * * (4.961)	0.641** (4.658)	0.657*** (3.259)	0.641*** (3.658)
Constant term	0.741 * * (3.232)	0.147 * * (3.236)	0.129 * * (4.236)	0.157 * * (3.369)	0.364 * (4.152)
Control variables	Y	Y	Y	Y	Y
Fixed time	Y	Y	Y	Y	Y
Enterprise fixation	Y	Y	Y	Y	Y
Region fixed	N	N	N	N	Y
Sample size	16082	8772	16082	16082	16082
R^2	0.354	0.254	0.521	0.241	0.354

Table 6: Mediation effect test

Variables	(1) innovation	(2) rd	(3) innovation
dcg	0.474 * * (3.751)	0.343 * * (4.558)	0.358 * * * (3.289)
rd			0.241 * * * (3.241)
Constant term	1.854* * (4.741)	0.661 * * * (3.741)	0.324 * * * (4.831)
Control variables	Y	Y	Y
Fixed time	Y	Y	Y
Business fixed	Y	Y	Y

Journal of Information Systems Engineering and Management
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Research Article

Sample size	16082	16082	16082
R^2	0.249	0.324	0.854

4.5 Heterogeneity test

1) Enterprise nature heterogeneity analysis

As shown in column (1) (2) of Table 6, there is a significant difference between the innovation performance of state-owned enterprises and non-state-owned enterprises in the digital era. It is found that due to their special status in the economic system, state-owned enterprises respond more positively to the level of digitalization, which significantly promotes the improvement of their innovation performance. This advantage may be due to soes' ability to allocate resources more efficiently, optimize operations, and keep up with national policy guidance, which effectively enhances their innovation capabilities and market competitiveness.

2) Heterogeneity analysis of enterprise types

As shown in columns (5) and (6) of Table 7, high-tech enterprises perform well in digital innovation, thanks to their sound infrastructure and ability to quickly integrate resources. Digital technology provides strong support for high-tech enterprises, promotes the optimal allocation of innovation resources, and significantly improves their innovation performance. Although non-high-tech enterprises also benefit from digitalization, the effect is relatively weak, which suggests that non-high-tech enterprises need to strengthen infrastructure construction and improve resource integration ability to make better use of digitalization to promote innovation.

Table 7: Heterogeneity analysis

Variables	(1) State-owned enterprises	(2) Non-state-owned enterprises	(3) Large enterprises	(4) Small business	(5) High-tech enterprises	(6) Non-high-tech enterprises
dcg	0.684 * (3.254)	0.254 * * (1.724)	0.684*** (4.325)	0.554*** (3.741)	0.452*** (4.587)	0.368*** (2.066)
Constant term	0.352 * * (3.058)	0.654 * * * (4.367)	0.751 * (3.258)	0.369 * * (4.269)	0.377 * * * (4.365)	0.765 * * * (3.589)
Control	Y	Y	Y	Y	Y	Y

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/

Research Article

variables						
Fixed time	Y	Y	Y	Y	Y	Y
Business fixed	Y	Y	Y	Y	Y	Y
Sample size	7236	8846	7881	8201	6272	9810
R^2	0.358	0.482	0.365	0.120	0.541	0.362

5. RESEARCH RESULTS

Leveraging comprehensive data from Chinese A-share high-tech enterprises spanning 2012 to 2024, this investigation employs robust baseline regression analysis and mediation effect modeling to derive the following significant conclusions:

Digital transformation, as a pivotal driver of organizational development in the contemporary era, demonstrates a substantial and consistent positive impact on innovation performance enhancement. This finding remains robust across multiple validation approaches, including alternative dependent variable specifications to assess measurement sensitivity, restricted sample periods to control for policy interventions, outlier treatment through winsorization, and extended model specifications to account for additional covariates.

The study reveals that digital maturity enhances innovation outcomes through three primary mechanisms: optimized resource allocation, improved operational efficiency, and accelerated technological advancement. These factors collectively strengthen organizational capacity for R&D investment, thereby driving innovation performance improvement. This insight not only expands the theoretical understanding of digital transformation's role in innovation ecosystems but also offers practical guidance for corporate strategy formulation.

6. POLICY RECOMMENDATIONS

6.1 Enterprise-Level Digital Maturity and Strengthening Digital Infrastructure

To reap the benefits of the digital transition, governments have to give priority to two parallel paths: upgrading the country's digital infrastructure, as well as helping firms to improve their technology. Research has consistently shown that digital adoption can boost innovation by increasing the efficiency of research and development and smarter allocation of resources. Specific measures should include:

- Expanding high-speed internet coverage nationwide
- Investment in Cloud Computing and Data Centre
- Development of specialized AI research centers
- Tax credits, subsidies, and subsidies for the adoption of technologies

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Research Article

- Develop targeted support schemes for SMEs facing digital costs
- Setting up a technology transfer scheme through a partnership between the government and the industry.

6.2 Increase investment in research and development and Financial Support Mechanisms

Our findings confirm that spending on research and development is a key link between digital tools and the success of innovation. To take advantage of this link, policymakers should:

- Increase direct financing of enterprise research and development projects
- Introduce low-cost innovative lending schemes
- Launch government-backed venture funds focusing on tech startups
- Increase tax credits for research spending in the private sector
- Working with banks to create flexible funding options for digital upgrades
- Enhance the protection of patents and copyrights to protect innovative investments.

6.3 Regulatory Adaptation and Fostering Digital Talent Development

Maintaining the digital transition requires the development of human capital as well as a sophisticated management approach. The main initiatives should include:

1. Education & Training:

- Boost STEM from the elementary level
- Implement national digital literacy programs
- Development of professional training in new technologies
- Promote University-Business Partnerships for Skills Development

2. The Regulatory Framework:

- Create adaptive policies that evolve in response to technological change
- Balance the needs of innovation with the protection of data privacy
- Create a "Safe Space" regulatory sandbox to test new technologies
- Set clear cyber security standards that do not stifle innovation

This multi-pronged approach will contribute to the creation of an innovative ecosystem in which digital transformation can thrive while managing potential risks. To promote sustainable technological progress, the recommendations combine immediate practical action with long-term structural improvements.

7. CONCLUSION

This study examines how digital change reshapes innovation in technological firms, revealing a double mechanism in which digital skills boost innovation both directly and indirectly by increasing expenditure on research and development. The results show that when firms adopt digital tools, they not only improve their existing business - they fundamentally change the way they deal with innovation. Digital systems remove operational barriers, enhance market awareness, and reduce the risks of

research investment, creating a virtuous circle in which each dollar invested in research results in higher returns.

There is considerable variation in the impact between different types of organizations. The government-backed companies take advantage of their political advantages to take the lead in digital innovation initiatives. Established companies use their financial power to scale digital solutions across their business, and technology experts are good at incorporating cutting-edge systems into their innovation pipeline. These differences highlight the need for tailor-made solutions, not a one-size-fits-all solution. The message for business leaders is clear: commitment to continuous digital investment pays off in innovation. Most successful companies view digital transition as a continuous process of updating systems, improving processes, and strategically expanding research budgets, rather than a one-off project. Governments can amplify these impacts by creating a supportive environment through smart policies that encourage the adoption of technology while managing risks.

A few caveats temper our conclusions. The focus of the study on large listed technology companies means that the experience of smaller operators may vary significantly. Follow-up research should cast a broader net across sectors and societies. Additionally, while our number-crunching reveals important patterns, it misses the human element - future work should blend statistical analysis with executive interviews to capture the cultural and managerial dimensions of digital transformation. Lastly, the research focuses on the short- to medium-term effects of digital transformation; however, digitalization may have long-term, lagged effects on innovation performance. Longitudinal studies examining the sustained impact of digital strategies would offer deeper insights into their long-run effectiveness.

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