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Research on the Impact of Digital Transformation on Corporate Innovation Performance

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Abstract. Vigorously developing the digital economy and promoting digital transformation is a strategic choice to seize new opportunities arising from the new wave of technological revolution and industrial transformation. Companies must actively advance the innovative development of the digital economy, strengthen, optimize, and expand their digital capabilities to enhance their technological innovation capacity. This paper takes Chinese A-share listed companies from 2010 to 2022 as the research sample, conducting an empirical analysis of the impact of digital transformation on corporate innovation performance. It further explores the mediating effect of increased investment in human capital, summarizing the influence path of "Digital Transformation—Human Capital Investment—Innovation Performance". The results show that digital transformation significantly enhances corporate innovation performance, empowering companies to improve their innovation outcomes. The impact of digital transformation on innovation performance varies by geographical location, ownership structure, and industry, with a more substantial effect on companies in the eastern region, non-state-owned enterprises, and high-tech firms. Based on these findings, the paper proposes feasible policy recommendations from both governmental and corporate perspectives.

Keywords: Digital Transformation; Innovation Performance; Human Capital Investment.

1. Introduction

The report from the 20th National Congress of the Communist Party of China emphasizes that, "High-quality development is the primary task in fully building a modern socialist country". In the collective study session of the 20th Central Political Bureau, General Secretary Xi Jinping further stated that, "Developing new productive forces is an inherent requirement and key focus for promoting high-quality development. We must continue to advance innovation and accelerate the development of new productive forces." As a new form of economic activity, the digital economy is characterized by high technological levels and strong innovation capabilities, playing a crucial role in enhancing technological innovation and driving high-quality economic development. In 2023, the digital economy accounted for 42.8% of China's GDP, highlighting its vital role in the national economy. With the rapid development and widespread application of information technology, digital transformation has become an unstoppable trend, profoundly altering corporate operational models, market competition dynamics, and the operational logic of the entire economic system. Digital transformation provides new momentum and support for the development of the digital economy. Its advancement not only promotes the robust growth of the digital economy but also facilitates the transformation and upgrading of the entire economy and society. Innovation is the primary driving force behind the development of the digital economy, and the 2024 Government Work Report once again emphasized the need to "actively advance the innovative development of the digital economy, fully unleashing its critical role in supporting high-quality economic development". Currently, China's digital economy operates within a competitive market, characterized by low market concentration and intense competition among numerous market participants. For companies to enhance their competitive advantage and achieve differentiation in products and services, they must redefine their market positioning and improve quality and efficiency through innovative development. In line with national development strategies and the promotion of comprehensive digital, networked, and intelligent transformation of the economy and society, this paper examines the impact and

mechanisms of digital transformation on corporate innovation performance, aiming to identify a new pathway that empowers the digital economy and fosters companies' creative transformation and innovative development.

The potential contributions of this research are as follows. First, it explores the impact of digital transformation on corporate innovation performance, enriching the body of research on the economic outcomes of corporate digital transformation and providing theoretical support for how digital technological innovation can drive high-quality corporate development, as well as offering references for future research design. Second, it adds to the empirical literature on factors influencing corporate innovation performance by introducing human capital investment and constructing a mediating model to examine the internal mechanism between digital transformation and innovation performance from a new perspective.

2. Literature Review

From the existing literature, scholars have developed a systematic understanding of digital transformation, creating a rich body of academic research that mainly focuses on the following areas. First is the concept of digital transformation. Vial G. (2019) defines digital transformation as the process in which enterprises use digital technologies to induce changes in organizational attributes, thereby improving the organization. Verhoef et al. (2021) identified three stages of digital transformation where the first stage involves converting analog information into digital information; the second stage is the process of using information technology or digital technology to change existing business processes; and the third stage goes beyond the mere alteration of processes and tasks, rearranging processes to change the business logic of the enterprise and achieve transformation. Xiao (2020) analyzed the differences between industrial and digital systems, pointing out that digital transformation is a fundamental and systemic change. Second are the drivers of digital transformation. Bresnahan et al. (1995) argue that the purpose of digital transformation is to improve organizational efficiency and achieve high-quality development for enterprises. Chen and Chi (2016) believe that rising labor costs and the dual pressures of resources and the environment drive enterprises to enhance competitiveness through transformation and upgrading. Jiao et al. (2021) explored the driving role of dynamic capabilities in digital transformation, discovering that enterprises continually perceive digital business opportunities and challenges during development, prompting them to integrate data resources and restructure internal and external organizational structures, thereby driving the digital transformation of business models and process management. Third is the path that affects the success of digital transformation. In the context of the digital economy, digital transformation has become an inevitable trend for enterprises. However, in practice, challenges such as the absence of strategy, blind imitation, and internal conflicts of interest remain, making it difficult to assess the effectiveness of digital transformation. This inevitably affects the confidence of enterprises in decision-making and subsequent investments. Many companies that adopt digital technologies do not achieve significant results from their transformation efforts (Chen et al., 2020). Therefore, some studies have shifted focus to how to improve the effectiveness of digital transformation, examining this from both internal and external perspectives. Zhao et al. (2021) pointed out that digital transformation can be driven by innovation in technology, organization, systems, and business, thereby improving transformation efficiency. The behavior of senior executives, as the primary decision-makers, also reflects in transformation practices. Characteristics such as academic experience, information technology background, age, professional background, and overseas experience of executives can have empowering effects on a company's digital transformation (Yang et al., 2022; Tang et al., 2022; Liu et al., 2023). Chen et al. (2021), focusing on corporate relations and behavioral factors, found that digital transformation exhibits a clear "peer effect", where leveraging peer influence helps companies make correct and reasonable strategic transformation decisions. Hu (2020) emphasized the impact of internal and external organizational factors on the success of transformation, suggesting that internal learning and building external networks can enhance transformation outcomes. Tang et al. (2022)

highlighted that increased government policy support and the implementation of prudent monetary policies to maximize interest rate liberalization can further assist digital transformation.

Lastly, the effects and mechanisms of corporate digital transformation have become a focal point of scholars' research. First is the economic impact on firms. From the perspective of the stock market, Wu et al. (2021) found that digital transformation significantly improves stock liquidity. In this process, the reduction of information asymmetry and the presence of favorable external conditions play a positive moderating role. From the financing and risk perspective, Wang et al. (2022) and Xiao et al. (2021) found that digital transformation alleviates financing constraints, reduces agency costs, and lowers the risk of corporate debt default. On the strategic management and decision-making aspect, as digital transformation deepens, inter-firm relations gradually shift from competition to symbiosis, focusing on co-creation and leading customer demand (Chen et al., 2019). Li et al. (2021) found that transformation helps companies popularize digital infrastructure and build digital capabilities, leveraging digital technologies to enhance supply chain integration. Xiao et al. (2021) also discovered that digital transformation enables companies to build digital communities, involving stakeholders in strategic decision-making, suppressing opportunistic behavior, and reinforcing collectivism. At the level of production efficiency, digital economy-related Total Factor Productivity (TFP) is a key indicator for measuring the new productive forces in the current phase of high-quality economic development. Digital transformation can raise TFP by enhancing technological innovation (Tu and Yan, 2022; Yang and Jiang, 2021). Liu et al. (2021) found that companies adopting digital management reforms can increase input-output efficiency and sustainably unlock the value of digital transformation. In terms of financial performance, researchers have employed various financial indicators to depict corporate earnings and core business performance from a comprehensive perspective. Their studies suggest that digital transformation can enhance corporate value, improve core business outcomes, and foster company growth (Ni and Liu, 2021; Huang et al., 2021; Yi, 2021). Apart from economic consequences, some studies have explored the non-economic effects of digital transformation. In the organizational structure aspect, under the digital economy, corporate structures are becoming more flattened and networked, with reduced barriers to information flow and accelerated resource integration. It fosters efficient coordination across the organization (Qi and Xiao, 2020). Digital transformation also impacts organizational empowerment by weakening the power of senior executives while strengthening grassroots authority, guiding a shift towards decentralization (Liu et al., 2020). Regarding the labor market, Xiao et al. (2022) revealed that digital transformation plays a key regulatory role in optimizing income distribution within the labor market. Huang et al. (2023) also indicated that digital technological innovation is driving the improvement of the labor resource structure, pushing companies toward high-quality development. From the perspective of customer demand, the application of digital technologies has heightened customer engagement in corporate production activities, placing greater emphasis on user experience. User value has truly become a guiding principle for corporate decision-making (Qi and Cai, 2020). From a corporate social responsibility standpoint, digital transformation reduces information asymmetry, encouraging companies to fulfill their responsibilities from the outset. It also enables precise targeting of customer needs, reducing resource waste and enhancing the ability to meet corporate social obligations (Shang and Wu, 2022). In the process of digital transformation, companies must adhere to sustainable development principles and improve their ESG performance (Wang, 2023).

A review of previous studies on digital transformation and corporate innovation performance reveals that most research focuses on theoretical perspectives, while studies on the mechanisms between digital transformation and innovation performance are relatively scarce. Although the development of the digital economy presents opportunities for innovation, it also introduces challenges. Li et al. (2022) found that enterprises adhering to a "go global" strategy, actively participating in global governance, and integrating into global innovation networks can improve innovation performance. Zhang and Long (2022), as well as Qiao and Zhang (2023), based on dynamic capability theory, explored how innovation capacity, absorptive capacity, and adaptive capacity function as intermediary mechanisms to promote corporate innovation. Digital transformation continues to

reshape organizational structures, fostering the upgrading of dynamic capabilities and stimulating innovation vitality, thus empowering corporate innovation. Huang et al. (2021) pointed out that improving both innovation capabilities and other management strategies within companies is essential for enhancing innovation performance. In addition, internal factors such as quality control, corporate social responsibility fulfillment, and entrepreneurial capabilities also act as mediating factors in the relationship between digital transformation and corporate innovation performance (Duan and Huang, 2022; Nie, 2023; Yu and Hu, 2022).

3. Theoretical Analysis and Hypothesis

3.1. Digital Transformation and Corporate Innovation Performance

The positive impact of digital transformation on corporate innovation performance is primarily reflected in the following three aspects.

First, there is significant improvement in management efficiency and mitigation of information asymmetry. On one hand, the digital infrastructure established through digital investment increases the supply of standardized information, facilitating smoother internal information flows. In this scenario, communication between managers and employees improves, reducing information asymmetry. This not only lowers the costs associated with communication and information transmission but also enables managers to make more precise and informed decisions based on comprehensive data, thus providing strong support for innovation activities. Additionally, the improved transparency of information promotes cross-departmental communication. Internal communication barriers within the company are dismantled, and the high-efficiency communication mechanisms established between different departments and teams help inspire new ideas, fostering the integration and collision of knowledge from various fields, thereby enriching the possibilities for innovation. On the other hand, digital transformation encourages companies to adopt more flexible and flat organizational structures (Qi and Xiao, 2020), shortening decision-making pathways and enabling quicker, more direct decisions. Innovation-related decisions can be translated into concrete actions more rapidly. Furthermore, the cross-departmental collaboration mechanisms supported by digital transformation facilitate effective information sharing and resource integration, thereby improving the overall efficiency and success rate of innovation projects.

Second, digital transformation enables precision marketing and real-time customer insights. Through the use of big data analysis, artificial intelligence, and other advanced technologies, companies can track market dynamics in real-time and accurately predict market trends and shifts in consumer demand. This allows for true user-driven innovation, where consumers provide innovative ideas based on their needs, which in turn become a key source of innovation for businesses (Hippel and V.E., 1977). By leveraging this precise market and consumer insight capability, firms can more clearly identify innovation directions, uncover new market opportunities, and spot potential innovation points. This reduces the risks and uncertainties in the innovation process and allows companies to formulate practical innovation strategies. The data-driven innovation model not only increases the success rate of innovation but also accelerates the commercialization of innovative outcomes. Using digital technologies, companies can complete the full cycle of product design, testing, and feedback in a short period, speeding up product innovation and iteration. Furthermore, by utilizing multiple digital channels, firms can maintain ongoing communication with consumers and continuously refine their products and services, leading to higher innovation performance and a stronger competitive edge in the market.

Third, digital transformation enhances corporate R&D innovation capabilities. At the core of digital transformation is the integration of advanced technologies such as big data, cloud computing, and artificial intelligence, which provide strong support for corporate R&D innovation. In terms of R&D processes, digital transformation drives the shift from traditional waterfall development models to modern approaches like DevOps, which emphasize rapid iteration and make the R&D process more

agile and efficient. By incorporating automation tools and intelligent platforms, companies can automate various stages of the R&D process, reducing human error and repetitive work while improving R&D efficiency and quality. As for enhancing innovation capabilities, the digital infrastructure built through digital investments effectively facilitates the integration of internal and external information, thus enhancing the company's technological innovation capacity. Based on this, the following hypothesis is proposed:

H1: Digital transformation can effectively enhance corporate innovation performance.

3.2. Mechanism of Digital Transformation's Impact on Corporate Innovation Performance

With the rapid development of the digital economy, companies not only need advanced technology and equipment but also a workforce with high digital literacy and innovation capabilities. In this context, human capital investment will inevitably increase, which in turn enhances the efficiency of other production factors used by the company, helping to stimulate innovation potential (Yang and Jiang, 2021). Sun et al. (2020) found that increased investment in technical human capital enables employees to identify and solve problems more quickly during R&D and innovation processes, having a positive impact on innovation activities. From the perspectives above, it is evident that by increasing human capital investment—such as by recruiting technical talent, offering professional training, providing continuous education, and optimizing the work environment—companies can acquire a group of professionals who are equipped with advanced technical and managerial knowledge. These individuals not only possess the expertise to proficiently utilize digital technologies but also play a critical role in the innovation process. Digital transformation requires companies to develop the ability to quickly adapt to and respond to environmental changes. Human capital investment, by enhancing employees' adaptability and flexibility, promotes the formation and development of a company's dynamic capabilities. These dynamic capabilities enable firms to maintain innovation momentum in fast-changing market environments, adjust strategic direction in a timely manner, and seize market opportunities, thus ensuring continuous improvements in innovation performance. Moreover, digital transformation compels businesses to continuously learn new knowledge and skills to keep pace with rapidly changing market conditions.

In addition, human capital investment facilitates knowledge sharing and communication within the organization, providing critical support for digital transformation. Companies can establish learning organizations that encourage employees to share and exchange knowledge, accelerating the accumulation and dissemination of internal knowledge. This process not only enhances employees' learning abilities and knowledge integration but also improves the organization's overall innovation and adaptability. In the digital transformation process, businesses must continuously learn and experiment, and human capital investment is a key driving force in this learning process.

Furthermore, human capital investment plays a crucial role in optimizing resource allocation and improving resource utilization efficiency. Digital transformation requires companies to reallocate and optimize their resource combinations to respond to rapidly changing market conditions and technological trends. As a unique resource, human capital possesses high levels of initiative and creativity. Highly qualified employees can better manage and utilize both internal and external resources, including capital, equipment, and technology, ensuring the smooth and efficient execution of R&D activities. For instance, they can reduce R&D costs and shorten development cycles by optimizing processes and increasing experimental efficiency, thereby creating more value for the firm. This resource optimization process, driven by human capital, not only increases resource utilization efficiency but also enhances the company's innovation capability and market competitiveness. Therefore, the following hypothesis is proposed:

H2: Digital transformation can enhance corporate innovation performance by increasing human capital investment.

4. Research Design

4.1. Sample and Source of Data

This study uses all A-share listed companies as the research sample, with a research period from 2010 to 2022. To ensure more robust research results, the data were processed as follows: (1) Companies under ST and *ST status were excluded; (2) All financial companies were excluded; (3) Companies with missing data for relevant variables were excluded. To mitigate the impact of extreme values on the analysis results, all continuous variables were winsorized at the 1% level. Data on corporate digitalization levels and innovation performance were obtained from the CSMAR database. After this processing, the final dataset includes 8,201 observations from 2,661 companies. The data processing software used in this study is Stata 18.

4.2. Definitions of Variables

(1) Dependent Variable: Corporate Innovation Performance (Innovate)

It is primarily measured by the number of patent outputs. Patent application types include those that have been applied for, authorized, cumulatively accepted by the end of the reporting period, and cumulatively authorized by the end of the reporting period, as well as those that have been obtained by the end of the reporting period. The cumulative number of patents obtained by the end of the reporting period provides a more comprehensive measure of the effects of corporate innovation investment. Therefore, this paper uses the natural logarithm of the cumulative number of patents, invention patents, utility model patents, and design patents obtained by the company by the end of the reporting period as the metric for corporate innovation performance.

(2) Core Independent Variable: Corporate Digital Transformation (Digital)

At present, foundational data technologies such as artificial intelligence, big data, cloud computing, and blockchain (commonly referred to as “ABCD” technologies) are developing rapidly. The integration of the digital economy with the real economy is continuously deepening, accelerating corporate innovations in production modes, product design, and R&D models (Qi & Xiao, 2020). However, the effectiveness of these transformations is difficult to measure through corporate financial indicators, making it challenging to obtain quantifiable metrics for digital transformation. Wu et al. (2021) employed the word frequency method, using annual reports of A-share listed companies to tally the frequency of keywords like artificial intelligence and big data. Due to the right-skewed nature of this data, they applied a logarithmic transformation. Generally, the higher the keyword frequency, the better it reflects the level of digital transformation within the company. This paper adopts Wu’s method and uses the transformed keyword frequency results as the measure for corporate digital transformation.

(3) Mediating Variable: Human Capital Investment (Researchnum)

Referring to relevant literature, there are multiple ways to measure human capital investment in corporate innovation activities, including direct and indirect methods. Direct measurement methods include the total number of R&D personnel and the proportion of R&D staff, while indirect methods include calculating the number of R&D projects and evaluating R&D efficiency and outcomes. This paper directly counts the total number of R&D personnel within the company, which is the most intuitive indicator for measuring R&D human capital investment. The natural logarithm of the total number of R&D personnel is used as the measure of human capital investment, with a higher value indicating stronger corporate R&D and innovation capabilities.

(4) Control Variables: To eliminate the interference of other factors on corporate innovation performance, this paper introduces a series of control variables, including return on assets (ROA), institutional shareholding proportion (Proportion), market-to-book ratio (MB), revenue growth rate (Growth), whether the company is loss-making (Loss), corporate assets (Size), and asset liability ratio (Lev).

Table 1 Definitions of Variables

Type	Name	Sign	Measurement Method
Dependent Variable	Corporate Innovation Performance	Innovate	It is the natural logarithm taken after adding 1 to the cumulative number of patents obtained at the end of the period.
Independent Variable	Corporate Digital Transformation	Digital	It is the natural logarithm taken after adding 1 to the total frequency of digital transformation keywords in the annual report of enterprises.
Mediating Variable	Human Capital Investment	Reseachnum	It is the natural logarithm taken after adding 1 to the number of R&D personnel in an enterprise
Control Variable	Return on Assets	Roa	Return on assets
	Institutional Shareholding Proportion	Proportion	Number of shares held by institutional investors/total number of shares
	Market-to-Book Ratio	MB	Book value/total market value
	Revenue Growth Rate	Growth	(Operating income of the current year-operating income of the previous year)/operating income of the previous year
	Loss or not	Loss	If the current year's net profit is less than 0, take 1, otherwise take 0.
	Corporate Assets	Size	Natural logarithm of total assets
	Asset Liability Ratio	Lev	Total liabilities/total assets

4.3. Design of Model

This paper primarily investigates the impact of digital transformation on corporate innovation performance and therefore constructs the following regression model:

$$\mathrm{Innovate}_{i,t} = \beta_0 + \beta_1 \times \mathrm{Digital}_{i,t} + \sum(\beta_k \times \mathrm{Control}_{i,t}) + \mu_{i,t}$$

Here, $\mathrm{Innovate}_{i,t}$ represents the innovation performance of firm *i* in year *t*, $\mathrm{Digital}_{i,t}$ represents the level of digitalization, $\mathrm{Control}_{i,t}$ includes the control variables mentioned earlier that may affect a firm's innovation performance, and $\mu_{i,t}$ is the random error term. This model is an empirical equation designed to test H1, controlling for both industry and year fixed effects and clustering at the firm level. If H1 holds, digital transformation should promote an improvement in innovation performance, and the coefficient β_1 should be significantly positive.

5. Analysis of Empirical Results

5.1. Descriptive Statistics

Table 2 presents the descriptive statistics of the main variables. The mean of innovation performance (Innovate) is 4.8689, with a standard deviation of 1.4038, indicating that there are differences in the number of cumulative patents obtained by the sampled firms, but the fluctuations are relatively small, which is generally consistent with previous research findings. The mean of digital transformation (Digital) is 3.1536, with a standard deviation of 1.2491, suggesting a larger variation in the degree of digital transformation among the sampled firms. The mean being higher than the median implies that some firms have a relatively high degree of digital transformation, further indicating significant differences in digital transformation levels across firms. Many firms are leveraging cutting-edge technologies as a driving force to capitalize on their advantages and achieve digitalization, while a minority of firms, constrained by the characteristics of their industries and lacking clear digital strategies, experience slower digital transformation processes and less significant results.

Table 2 Descriptive Statistics of Variables

Variable	Mean	SD	p25	p50	p75
Innovate	4.8689	1.4038	3.9703	4.9200	5.7777
Digital	3.1536	1.2491	2.3026	3.0910	4.0073
Roa	0.0462	0.0617	0.0210	0.0481	0.0772
Proportion	0.1000	0.1748	0.0060	0.0253	0.0910
MB	0.5819	0.2185	0.4179	0.5870	0.7430
Growth	0.2101	0.0126	0.2011	0.2085	0.2170
Loss	0.0838	0.2771	0.0000	0.0000	0.0000
Size	21.7269	1.0861	20.9487	21.5517	22.2885
Lev	0.3521	0.1933	0.1940	0.3314	0.4871

5.2. Benchmark Regression

To examine the impact of digital transformation on corporate innovation performance, this paper controls for year and industry fixed effects and conducts a regression analysis based on the previously constructed model. Control variables are also included to test whether the regression results remain consistent. Table 3 presents the regression results for the full sample. Column (1) includes only the core explanatory variable, while Column (2) includes all control variables. The results show that all regression coefficients are significantly positive. Additionally, the study finds that the coefficient in Column (1), where only the core explanatory variable is included, is larger. After adding the control variables, the coefficient decreases, indicating that the regression results in Column (1) underestimate the influence of other control variables on innovation performance. Ultimately, the regression coefficient for digital transformation and innovation performance is 0.287, significant at the 1% level, indicating that digital transformation can significantly enhance corporate innovation performance. From an economic perspective, for every one percentage point increase in the degree of digital transformation, innovation performance increases by 0.287 percentage points. Therefore, H1 is confirmed.

Table 3 Benchmark Regression Result

	(1) Innovate	(2) Innovate
Digital	0.287*** (11.14)	0.164*** (7.29)
Roa		-0.574 (-1.37)
Proportion		-0.160** (-2.15)
MB		-0.159 (-1.57)
Growth		23.030*** (4.02)
Loss		0.091 (1.42)
Size		0.351*** (5.82)
Lev		-0.450*** (-3.10)
_cons	3.965*** (49.84)	-7.828*** (-13.06)
Field	Control	Control
Year	Control	Control
N	8201	8201
R^2	0.297	0.437

5.3. Robustness Test

5.3.1. Endogeneity Test

There may be a bidirectional causal relationship between corporate digital transformation and innovation performance. On the one hand, digital transformation provides strong technical support and a driving force for corporate innovation, thereby significantly enhancing innovation performance. On the other hand, the improvement in innovation performance may bring more market opportunities and competitive advantages to firms, further stimulating their willingness and motivation to pursue digital transformation. Additionally, there may be an issue of omitted variables in this study. To address the endogeneity problem, this paper follows the method of Yin et al. (2022), applying a one-period lag to the core explanatory variable (Digital) and conducting a new regression analysis. The robustness test results are presented in Table 4. In the results of Column (1), the coefficient for digital transformation remains significantly positive, indicating that the results remain significant even after considering the endogeneity issue, thus confirming the robustness of the previous baseline regression results.

Table 4 Endogeneity Test

	(1) Innovate
L.Digital	0.001*** (3.75)
Roa	-0.602 (-1.52)
Proportion	-0.205** (-2.17)
MB	-0.100 (-1.02)
Growth	25.526*** (7.60)
Loss	0.127 (1.56)
Size	0.373*** (9.89)
Lev	-0.540*** (-4.54)
_cons	-8.302*** (-20.72)
Field	Control
Year	Control
N	4662
R^2	0.441

5.3.2. Substitution of Explanatory Variables

To further measure corporate digital transformation, this paper also incorporates data from the annual reports of A-share listed companies, summing the frequency of sentences containing keywords such as artificial intelligence and big data. The number of sentences with these keywords (Digital2) is used as an explanatory variable, which is reintroduced into the model for regression analysis. The results indicate that the model passes the significance test at the 1% level, and the main conclusions remain valid, demonstrating the robustness of the previous findings. The detailed regression results are shown in Table 5.

Table 5 Substitution of Explanatory Variables

	(1) Innovate
Digital2	0.002*** (2.97)
Roa	-0.595 (-1.44)
Proportion	-0.161** (-2.16)
MB	-0.173* (-1.67)
Growth	23.350*** (4.06)
Loss	0.083 (1.30)
Size	0.372*** (6.13)
Lev	-0.463*** (-3.14)
_cons	-7.893*** (-12.96)
Field	Control
Year	Control
N	8201
R^2	0.428

5.4. Influence Mechanism Test

To further examine whether digital transformation can influence a firm's innovation performance by increasing human capital investment, this section employs a mediation effect model, using the number of R&D personnel as a mediating variable, to conduct an empirical test of the impact mechanism. The results in Table 6 indicate that digital transformation can enhance a firm's innovation performance through the mediating mechanism of increasing human capital investment (Researchnum). Specifically, in column (2) of Table 6, the coefficient of Digital is -0.01, which is not significant and shows a negative correlation, meaning that having fewer R&D personnel does not improve innovation performance and may even hinder a firm's innovation activities. In column (1), the coefficient of Digital is 0.047 and is significant at the 5% statistical level, indicating that having a larger number of R&D personnel significantly promotes innovation performance. Thus, human capital investment plays a clear mediating role in the process by which digital transformation affects innovation performance, and Hypothesis H2 is confirmed.

Table 6 Influence Mechanism Test

	(1) High Reseachnum Innovate	(2) Low Reseachnum Innovate
Digital	0.047** (2.32)	-0.010 (-0.15)
Roa	-0.399 (-1.55)	-1.142 (-0.72)
Proportion	-0.066 (-1.18)	0.056 (0.29)
MB	-0.018 (-0.21)	-0.087 (-0.27)
Growth	18.620*** (4.10)	23.314 (1.16)
Loss	0.073* (1.92)	-0.205 (-1.43)
Size	0.219*** (3.80)	0.240* (1.70)
Lev	-0.008 (-0.05)	0.240 (0.51)
_cons	-3.797*** (-3.73)	-5.618 (-1.22)
Field	Control	Control
Year	Control	Control
N	6378	424
R^2	0.858	0.920

5.5. Heterogeneity Analysis

The impact of digital transformation on a firm's innovation performance may exhibit differentiated characteristics due to variations in ownership structure, geographical location, or industry type. This paper conducts heterogeneity tests from these three perspectives to further analyze the relationship between digital transformation and corporate innovation performance.

Group regression by the region where the firm is located. The geographical location of the firms is divided into eastern and non-eastern regions for heterogeneity analysis. The results in Table 7 show that digital transformation has a significant positive effect on the innovation performance of firms in the eastern region, while the impact on firms in non-eastern regions is not significant. A possible reason for this result is the uneven economic development between the eastern and western regions of China, leading to differences in digital infrastructure. Firms in the eastern region have made substantial investments in digital transformation, with relatively well-developed digital infrastructure

and abundant digital talent resources. In contrast, the economic foundation in non-eastern regions is relatively weaker, with insufficient digital infrastructure and a shortage of digital talent, resulting in slower progress in digital transformation and a more limited effect on improving innovation performance.

Table7 Heterogeneity Analysis Based on Geographical Location

	(1) eastern regions Innovate	(2) non-eastern regions Innovate
Digital	0.158*** (5.71)	-0.028 (-0.69)
Roa	-0.770 (-1.45)	-0.126 (-0.24)
Proportion	-0.120 (-1.39)	-0.091 (-0.79)
MB	-0.236** (-2.00)	0.190 (1.16)
Growth	25.098*** (3.39)	18.515** (2.13)
Loss	0.094 (1.16)	0.049 (0.75)
Size	0.344*** (4.52)	0.150 (1.50)
Lev	-0.438** (-2.42)	0.154 (0.58)
_cons	-8.032*** (-11.73)	-2.385 (-1.33)
Field	Control	Control
Year	Control	Control
N	6114	1851
R^2	0.436	0.825

Group regression by ownership structure. Firms are categorized into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) for heterogeneity analysis. The results in column (1) of Table 8 show that the regression coefficient of Digital is 0.101, significant at the 10% confidence level, indicating that digital transformation can enhance the innovation performance of SOEs. In column (2), the coefficient of Digital is 0.164 and significant at the 1% level, showing that digital transformation has a significant positive effect on the innovation performance of non-SOEs. Although both types of enterprises experience positive effects, the coefficient for non-SOEs is higher in comparison. This is primarily because SOEs are often subject to stricter institutional and regulatory constraints, which may result in a lack of flexibility and autonomy in the innovation process. Digital transformation requires firms to respond quickly to market changes and adjust strategies flexibly, so the relatively cumbersome decision-making processes in SOEs may, to some extent, hinder improvements in innovation performance. Compared to SOEs, non-SOEs typically enjoy greater flexibility and autonomy, allowing them to more effectively capture market opportunities, respond quickly to market changes, and adjust business strategies. This flexibility and autonomy enable non-SOEs to actively explore innovative paths during the transformation process and fully leverage the advantages of digital technology to enhance innovation performance.

Table 8 Heterogeneity Analysis Based on Ownership

	(1) SOE Innovate	(2) Non-SOE Innovate
Digital	0.101* (1.81)	0.164*** (6.76)
Roa	0.474 (0.46)	-0.487 (-1.06)
Proportion	0.106 (0.66)	-0.234*** (-2.86)
MB	0.053 (0.20)	-0.195* (-1.72)
Growth	18.944 (1.54)	21.648*** (3.49)
Loss	0.224* (1.65)	0.107 (1.47)
Size	0.581*** (4.57)	0.320*** (4.89)
Lev	-1.059*** (-3.11)	-0.241 (-1.52)
_cons	-12.075*** (-8.79)	-6.875*** (-10.27)
Field	Control	Control
Year	Control	Control
N	1312	6805
R^2	0.610	0.403

Group regression by whether the firm belongs to a high-tech industry, with detailed results shown in Table 9. In column (1), the coefficient of Digital is 0.175, significant at the 1% confidence level. In column (2), the coefficient of Digital is 0.081, but its impact is not significant. Comparing the two sets of data, the coefficient for high-tech firms is higher, indicating that digital transformation has a more pronounced effect on enhancing their innovation performance. This may be because high-tech industries, as representatives of technology-intensive sectors, rely heavily on continuous technological innovation and product development as their core competitive advantage. Digital technologies provide strong technical support for these industries, enabling firms to improve R&D efficiency, accelerate product innovation, and drive business model innovation through the application of advanced technologies. As a result, high-tech firms are able to realize improvements in innovation performance more rapidly during digital transformation, further solidifying their market leadership position.

Table 9 Heterogeneity Analysis Based on Industry

	(1) High-tech Industry Innovate	(2) Non-high-tech Industry Innovate
Digital	0.175*** (7.31)	0.081 (1.08)
Roa	-0.587 (-1.30)	0.238 (0.23)
Proportion	-0.179** (-2.27)	-0.087 (-0.35)
MB	-0.095 (-0.89)	-0.622* (-1.93)
Growth	19.747*** (3.27)	24.064 (1.46)
Loss	0.122* (1.86)	-0.072 (-0.34)
Size	0.407*** (6.54)	0.241 (1.37)
Lev	-0.502*** (-3.36)	0.350 (0.66)
_cons	-8.349*** (-13.48)	-5.764*** (-3.25)
Field	Control	Control
Year	Control	Control
N	7151	1034
R^2	0.457	0.425

6. Conclusion and Suggestions

Based on data from Chinese A-share listed companies from 2010 to 2022 in the CSMAR database, this paper explores the impact and mechanism of digital transformation on corporate innovation performance from both theoretical and empirical perspectives. The research findings indicate the following three argument. Overall, digital transformation significantly enhances corporate innovation performance, and this conclusion remains robust after multiple robustness checks. In terms of mechanism, the study finds that digital transformation significantly boosts innovation performance by increasing human capital investment, identifying the path of "digital transformation-human capital investment-innovation performance". in terms of heterogeneity, the impact of digital transformation on innovation performance varies across regions, ownership structures, and industries. Specifically, it has a more pronounced effect on firms in the eastern region, non-state-owned enterprises, and high-tech enterprises. Based on these conclusions, the following recommendations are proposed.

From the government perspective, considering the differences in the needs and capacities for digital transformation across industries and firms of varying sizes, the government should implement differentiated support policies. For example, more financial subsidies and tax incentives should be offered to small and medium-sized enterprises, while more R&D funding and intellectual property protection should be provided to high-tech firms. As digital transformation continues to develop, market demands and technological trends will keep evolving. The government should establish a dynamic policy adjustment mechanism, allowing policies to be timely updated based on market feedback and technological advancements to ensure their relevance and effectiveness. Given the relatively weak digital transformation foundations in the central and western regions, the government should increase investment in infrastructure, such as improving network coverage and building data centers, while also encouraging eastern firms to transfer parts of their industrial chains to the west, promoting digital transformation through coordinated industrial development. Additionally, leading firms should be encouraged to share solutions and drive digital transformation across the entire supply chain. In regions with distinct industrial characteristics and pressing transformation needs, smart manufacturing pilot zones should be established. Moreover, the development of digital transformation in enterprises depends on strong foundational support and a conducive environment. The government could establish a multifunctional digital regulatory system with capabilities such as monitoring and early warning, information disclosure, big data collection, and public evaluation. This system would help clarify boundaries, protect rights, and ensure the innovation and application of digital technologies, thereby promoting the digitalization of industries.

From the enterprise perspective, first, firms should clearly define their strategic direction and long-term goals for digital transformation, recognizing that this involves not only technological upgrades but also a fundamental reshaping of corporate strategic thinking. Management should integrate industry trends, market changes, and the firm's strengths to develop forward-looking and feasible transformation strategies. Second, companies must accelerate the reform of traditional organizational structures and business processes, establishing cross-departmental collaboration mechanisms to facilitate efficient resource allocation. In terms of process optimization, digital tools should be used to automate business processes and improve execution efficiency. Moreover, firms should continually increase investment in cutting-edge technologies such as cloud computing, big data, and artificial intelligence, focusing not only on technological advancement but also on the practicality and deep integration of these technologies with their business. Internal R&D teams should be encouraged to collaborate with external technology partners to explore new application scenarios, using technological innovation to drive product and service upgrades, thereby enhancing innovation performance and market competitiveness. At the same time, firms should focus on building strong technical teams by recruiting and developing talent with digital skills. Collaborations with universities and research institutions can be established to introduce high-quality external educational resources, providing employees with advanced knowledge and technical training. This investment in human capital will offer a solid talent foundation for the company's digital transformation. Lastly, firms should strengthen collaboration with upstream and downstream businesses within the supply chain,

jointly creating an open digital ecosystem. Through resource sharing and collaborative innovation, firms can accelerate development in technology R&D and market expansion. The construction of a digital ecosystem will enable positive interaction between firms and the external environment, providing continuous momentum for digital transformation and innovation-driven growth.

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