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Impact of digital economy on enterprise innovation in China: Evidence from a panel data set of Chinese companies

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ABSTRACT

As a new driving force for high-quality development, the digital economy is reshaping knowledge diffusion and corporate innovation models, becoming a key force in optimizing resource allocation, improving operational efficiency, and driving innovation. This paper uses data from a sample of 30,391 Chinese enterprises from 2015 to 2022, employing a two-way fixed-effects model and a mediation effect model to empirically examine the impact of the development of the digital economy on innovation in Chinese enterprises. The results show that the digital economy significantly increases patent applications, confirming its role as a catalyst for corporate innovation. Mechanism analysis suggests that R&D investment plays a mediating role of approximately 20%, highlighting its importance in transforming digitalization into innovative outcomes. Heterogeneity analysis further demonstrates that this effect is more pronounced in non-state-owned enterprises. At the industry level, health and social work, wholesale and retail, and manufacturing benefited the most, while real estate and construction were negatively impacted. The contributions of this study are: first, it expands the empirical research on the relationship between the digital economy and innovation, providing a new perspective for digital empowerment of innovation; second, it identifies R&D investment as a significant mediating mechanism, deepening our understanding of the innovation-driven mechanism; third, through heterogeneity analysis, it highlights industry and ownership differences, providing a reference for differentiated policy making.

Contribution/ Originality: Based on micro-data, this research enriches the understanding of the impact of the digital economy on innovation and emphasizes the importance of corporate R&D investment. Furthermore, the study finds that the digital economy has the greatest effect on non-state-owned enterprises and exerts a negative impact on the real estate and construction industries.

1. INTRODUCTION

1.1. Research Background

The digital economy, which emerged in the 1990s, represents a new economic model driven by the networking of human intelligence and advances in digital information technology (Teece, 2018). The digital economy has undergone rapid growth. This expansion is largely attributable to the widespread digital transformation occurring across industrial sectors (Kewsuwun, 2020). The modern information network now serves as a pivotal force in altering the global competitive environment. The digital sector in China, in particular, has shown remarkable development momentum. By 2022, the scale of digital economic activities in China reached 50.2 trillion yuan, representing 41.5% of the national GDP after growing 10.3% year-on-year. Within this total, 41 trillion yuan came from industrial digitalisation and 9.2 trillion from digital industrialisation; these amounts account for 18.3% and 81.7% of the total, respectively. These figures highlight the central function of the digital economy as a key enabler of China's macroeconomic growth. A growing consensus suggests that digital economic mechanisms are fundamentally altering industrial structures, blurring conventional sectoral boundaries, and redefining inter-industry collaborative models (Shi & Wei, 2025).

The global economy has been profoundly reshaped by the rapid evolution of digital technologies, giving rise to what is now known as the digital economy. It encompasses a broad spectrum of economic activities that are based on digital technologies, including e-commerce, digital payments, online platforms, and the utilization of big data and AI. The digital economy can enhance firm innovation. It fosters an environment conducive to innovation by providing access to vast amounts of data, advanced analytical tools, and collaborative platforms. Firms can leverage these resources to create novel offerings, services, and operational frameworks (Westerman, Bonnet, & McAfee, 2014). Digital economy significantly enhances firm innovation through several key mechanisms, such as enhanced digital capability, strategic digital orientation, comprehensive digital transformation, and targeted digital innovation (Shah, Zehri, Saraih, Abdelwahed, & Soomro, 2024). Furthermore, digital platforms allow firms to transcend geographic constraints, providing access to worldwide markets. This global reach not only increases sales but also helps firms to diversify their markets and reduce dependency on local demand (Manyika, Lund, DC, & Bughin, 2016). Despite rapid expansion and demonstrated potential, a thorough understanding of how the digital economy specifically influences enterprise innovation remains underdeveloped. Although significant research has explored the digital economy's effects across various economic domains, a notable gap persists concerning its impact on innovation within firms, especially in the context of China.

1.2. Research Objectives

We employ panel data from listed firms spanning 2015 to 2022 to examine the intrinsic influence of the digital economy on corporate innovation. The research focuses on three key aspects: (1) analyzing the immediate linkage between the progression of the digital economy and innovation outcomes; (2) determining whether elevated R&D expenditure acts as an intermediary mechanism through which digital economic conditions bolster innovation; (3) examining variation in innovative responses to digital economy exposure among firms with different characteristics.

2. LITERATURE REVIEW

2.1. Measurement of Digital Economy Development

Research on the digital economy necessitates accurate measurement of its development. Russo (2019) introduces the Digital Economy and Society Index (DESI) as an integrated instrument designed to measure digital progress across European countries. DESI assesses national performance across multiple dimensions such as connectivity, human capital, utilization of internet services, adoption of digital technologies, and digital public service provision. This index offers empirical benchmarks that assist policymakers in strengthening digital infrastructure and capabilities. Moroz (2017) conducts a comparative analysis of its development in Poland alongside Germany, Italy, Lithuania, and Slovakia from 2002 to 2016. The study relies on secondary data and statistical methods, using two composite indexes: the NRI and the DESI. These indexes assess development across infrastructure, affordability, usage, human capital, and digital services. Poland showed moderate performance in affordability and infrastructure but ranked lowest in categories like ICT impact and usage. The findings reveal that Poland lags behind its European peers in leveraging ICT for economic and social benefits. Chereshnia (2023) constructs a Digital Economy Index to assess national and sub-national digital development across Russian regions and European countries, using data primarily from 2019.

2.2. Factors Affecting the Digital Economy

Current studies indicate that the growth of the digital economy exhibits both universal patterns and significant contextual variations. Benčič, Kitsay, Karbekova, and Giyazov (2019) found that developed countries have significant advantages in digital innovation and infrastructure, while developing countries are constrained by the digital divide, insufficient access to technology, and imperfect institutions. Therefore, differentiated strategies need to be formulated based on regional realities. Karieva, Akhmetshina, and Fokina (2021) highlighted that governmental policies, investments in digital infrastructure, and educational initiatives for digital skills are essential drivers for Russia's digital economy, also stressing the value of collaboration between public and private entities. Loh et al. (2021) believe that Malaysia's Digital Free Trade Zone (DFTZ) policy and fintech ecosystem have played a positive role in promoting enterprise digitalization, but insufficient digital literacy and weak infrastructure have constrained its inclusive growth. Unlike the policy-driven approach, Mammadova and Mammadov (2022) observed that in Azerbaijan, the COVID-19 pandemic acted as a catalyst for digital adoption, boosting the use of online services, e-commerce, teleworking, and digital payments. Chinese researchers have placed greater emphasis on internal mechanisms and geographical imbalances. For instance, Chen (2021) identified human capital, road density, per capita GDP, and government R&D spending as major determinants of urban digital economic performance, with innovation and economic development being pivotal. Using a geographically weighted regression model, Li and Liu (2021) uncovered regional variations in how factor inputs, technological advances, and institutional reforms shape digital economic development, advocating for region-specific policies. Shao, Lu, Lin, Chen, and Liou (2025) developed an evaluation framework underscoring the significance of regional economic conditions, corporate innovation environment, and the digital gap, particularly stressing socioeconomic dimensions for the sustainability of digital economies in developing nations. In summary, policy backing, infrastructural advancement, and innovative capacity serve as common catalysts, while external disruptions and regional disparities significantly affect the evolutionary path of the contemporary digital economy.

2.3. The Impact of Digital Economy on Economy and Society

The advancement of it is profoundly changing the economic, social, and environmental landscape. Its impact has both common laws and significant situational differences. Existing literature has revealed the multi-tiered mechanisms through which digitalization operates across various domains, particularly in economic growth, carbon emissions, and innovation.

(1) Digital Economy and Economic Growth. Russo (2019) demonstrated a strong correlation between higher Digital Economy and Society Index (DESI) scores and improvements in economic output, employment, and quality of life. Digitalization enhances productivity by reducing costs, streamlining processes, and expanding income sources. Abendin and Duan (2021) highlighted that it significantly amplifies the positive effect of international trade on economic development within African nations. Bakaev, Atabaev, and Sobirov (2022) showed, based on data from Uzbekistan, that ICT infrastructure, e-commerce, and digital public services exert a favorable influence on GDP growth. In a study covering 31 countries participating in the Belt and Road Initiative, Zhang et al. (2022) demonstrated that a one-unit increase in the digital economy corresponds to an increase in per capita GDP ranging from 0.36% to 1.51%. This effect primarily operates through industrial structure upgrading, a reduction in unemployment, and higher employment within the service sector. Using provincial data from China, Miao, Li, and Wu (2024) revealed that the digital economy mitigates competitive pressure among local governments and facilitates more balanced regional development by improving trade openness and stimulating entrepreneurial activity, with particularly noticeable benefits in less developed areas. Further reinforcing these findings, Chen and Xing (2025) employed prefecture-level city data to illustrate that the digital economy not only directly stimulates economic expansion but also enhances the quality of development via substantive and strategic green innovation. Their findings indicated a more pronounced mediating role of green innovation in eastern regions and major urban centers.

(2) Digital economy and carbon emissions. Recent research has examined the complex and dual role of digital economic development in influencing carbon emissions from multiple perspectives. Shen, Wang, Wu, and Shen (2024) observed that although digital expansion initially elevates total carbon emissions mainly due to energy-intensive digital infrastructure construction it concurrently encourages green production and industrial upgrading, leading to a notable decline in carbon emission intensity and demonstrating positive spatial spillover effects. Further supporting this, Sun and Wu (2024) concluded that it exerts an overall suppressive influence on carbon emissions, with industrial digitization being the most impactful component, particularly in high-emission areas and western regions. At the city level, Xie, Liu, and Dwivedi (2024) identified an inverted U-shaped relationship based on a sample of 267 prefecture-level cities: early-phase digital infrastructure increased emissions, whereas long-term benefits included improved industrial efficiency and a cleaner tertiary sector, ultimately reducing emissions with observable spatial diffusion. Focusing on the agricultural sector, Li, Sheng, Zhang, and Wang (2024) revealed that digitalization significantly mitigates agricultural carbon emissions, mediated through technological innovation and also exhibiting significant cross-regional spillover effects.

(3) Digital economy and innovation. Zhang, Liu, and Yang (2024) revealed that digital advancement substantially boosts urban innovation performance, primarily facilitated by industrial restructuring, and yields more pronounced benefits in central and eastern regions as well as in substantive innovation domains. Xu, Shan, Li, Chen, and Zhou (2023) emphasized the role of knowledge spillovers, experiential learning, and independent R&D in fostering real-economy innovation through digitalization, though they also noted a stronger innovative response in developed areas, with less-developed regions experiencing limited or even slightly adverse outcomes. Further corroborating its positive influence, Dai, Fan, Wang, and Xie (2022) identified that digital economic development significantly elevates green patent output, largely mediated through increased investment in capital and technical talent, with more substantial effects observed in eastern China. Tang, Ren, and Zhou (2022) studied rural tourism innovation and entrepreneurship and found that the Rural Economic Digitalization Index (REDI) reduces innovation costs by improving information access, digital financing, and collaborative platforms, cultivates differentiated products, and enhances entrepreneurial sustainability. Overall, the digital economy promotes innovation at all levels by optimizing resource allocation, reducing innovation costs, and stimulating R&D investment, while showing obvious regional heterogeneity. In summary, prior research has predominantly concentrated on evaluating the development level of the digital economy and identifying its determinants, uncovering its multifaceted impacts on economic growth, environmental sustainability, and innovation capacity. Nonetheless, there remains a scarcity of studies that systematically investigate the influence of the digital economy on corporate innovation. Using panel data from Chinese enterprises between 2015 and 2022 to empirically examine the intrinsic relationship between the progression of the digital economy and firm-level innovation, the study makes contributions in three primary areas: (1) Theoretical perspective: By framing digital economy development as a central driver, this paper elucidates its underlying mechanisms shaping corporate innovation, thereby providing empirical support for theories related to digital capability, digital orientation, and innovation-driven transformation; (2) Mechanistic insight: It verifies that R&D expenditure acts as a significant intervening factor in the connection between digital economic activities and innovation outcomes in firms, and further investigates the role of moderating variables; (3) Practical and policy relevance: The findings offer actionable insights for corporate strategy including technology investment, resource allocation, and organizational adaptation and supply empirical evidence to help policymakers in emerging economies design effective digital innovation policies aimed at enhancing firms' competitive edge and sustainable development.

3. THEORETICAL ANALYSIS

3.1. Direct Influence of the Digital Economy on Corporate Innovation

The widespread adoption of emerging digital technologies such as big data, cloud computing, artificial intelligence, and blockchain has positioned the digital economy as a fundamental driver of corporate innovation. From one perspective, it considerably lowers the expenses related to information search and transmission (Chen, 2020), allowing firms to efficiently gather multi-dimensional intelligence pertaining to market needs, industrial developments, and advanced technologies. This, in turn, supports more informed innovation-related decision-making. Simultaneously, digital platforms and open innovation ecosystems create opportunities for cross-boundary cooperation and resource sharing (Yang, Chen, & Chen, 2023). Companies can utilize online environments to facilitate technology interchange and accelerate the commercialization of research outcomes, transcending the limitations typical of conventional research and development settings. Moreover, the adoption of digital tools enhances the effectiveness of internal resource management and diminishes innovation-related uncertainties and risks via smart manufacturing, refined governance, and data-informed R&D processes.

H1: The development of the digital economy has significantly improved the innovation capacity of enterprises.

3.2. The Indirect Impact of the Digital Economy on Corporate Innovation

The proliferation of digital technologies has fundamentally reshaped how firms access resources and conduct innovation. A key mechanism lies in the alleviation of financing constraints. By leveraging big data analytics for risk assessment, blockchain for credit verification, and online financial platforms, corporate credit information becomes more accessible and reliable. This transparency mitigates information asymmetry and adverse selection, thereby facilitating lending decisions and enhancing firms' ability to secure necessary funding for R&D projects (Li, Wang, Zhou, Wang, & Mardani, 2023).

Furthermore, the digital economy enhances resource allocation efficiency and reduces transactional overhead. These efficiencies enable enterprises to reallocate capital and effort from non-productive activities toward core research and development endeavors (Peng & Luxin, 2022).

Additionally, digital environments foster knowledge sharing and collaborative networks, which raise the marginal output of R&D investments and strengthen corporate incentives to innovate. Sustained R&D expenditure not only supplies essential financial and technical support but also helps cultivate specialized talent and accumulate innovative experience, creating a self-reinforcing cycle of capability building.

H2: Corporate R&D investment mediates the relationship between digital economic development and innovation capabilities.

4. METHODOLOGY AND DATA

4.1. Model Construction

The baseline model is specified as follows.

$$RD_{it} = a_0 + a_1 DIG_{it} + a_x Control_{it} + \delta_i + \tau_t + \varepsilon_{it} \qquad (1)$$

Here, it indicates firm i in time period t. RD stands for the company's patent number based on research and development. DIG indicates the digital economy index in the firm's local city. α is the regression coefficient. δi and τt represent industry and year fixed effects, respectively; ε reflects unobserved idiosyncratic shocks.

The mediation model is proposed, consisting of the following equations.

$$IN_{it} = \beta_0 + \beta_1 DIG_{it} + \beta_x Control_{it} + \delta_i + \tau_t + \varepsilon_{it} \qquad (2)$$

$$RD_{it} = \pi_0 + \pi_1 DIG_{it} + \pi_2 IN_{it} + \pi_x Control_{it} + \delta_i + \tau_t + \varepsilon_{it} \qquad (3)$$

Here, IN indicates firm research and development investment. β and π are the regression coefficients of each variable.

4.2. Data

4.2.1. Dependent Variables

In this study, innovation (RD), which is denoted by firms' patent numbers, is selected as the main dependent variable.

4.2.2. Independent Variable

The digital economy (DIG) constitutes the core independent variable in this research. Given the urban focus of this study, we adopt the methodology proposed by Liu, Yang, Li, and Zhong (2022) to construct a multi-dimensional digital economy index. The entropy method is applied to determine indicator weights, enabling a comprehensive evaluation of urban digital economic development. Table 1 outlines the specific indicators, their interpretations, and data sources utilized in this study.

Table 1. Digital economy index.

	Indicators	**Meaning**	**Source**
Total index	Internet penetration	Number of Internet broadband subscriptions per 100 people	Statistical Yearbook
	Internet-related practitioners	Proportion of employees in computer services and software industries	
	Internet-related outputs	Per capita telecommunications business volume	
	Cell phone penetration rate	Number of mobile phone subscribers per 100 people	
	Digital Inclusive Finance Index	Comprehensive index developed by Peking University	Peking University Digital Finance Database

4.2.3. Mediating Variable

Firm's investment in R&D is used as a mediating variable in this study. The digital economy, through its integration with economic development, is widely recognized for creating a siphon effect on human capital, thereby securing the manpower necessary for R&D investment. This development enhances societal participation in innovation, boosts the innovation talent pool, and increases R&D investment, which in turn drives technological progress (Yan & Wu, 2021). Higher R&D investments stimulate enterprise enthusiasm for innovation, help mitigate risks associated with R&D activities, and increase R&D outputs (Zhang & Lu, 2014). Investment in information technology R&D is crucial for economic output and productivity growth, with long-term investments leading to sustained enterprise development, provided that the R&D direction is correctly aligned (Cem, 2011). Additionally, when human capital aligns with R&D funding, these investments can be effectively converted into advanced technological achievements, fostering progress in areas such as technology transfer and green technology (Ji & Sun, 2021).

4.2.4. Control Variables

(1) Firm size, represented by total firm employees, is selected as a control variable in this research. Larger firms benefit from economies of scale in R&D, allowing them to undertake significant and riskier innovation projects that smaller firms might avoid (Shefer & Frenkel, 2005). Larger firms typically have more extensive networks and better access to external knowledge and technologies, enhancing their innovation capabilities (Vaona & Pianta, 2008). (2) Firm cash flow. Ample internal cash flow provides essential financial slack, alleviating constraints on R&D investment and enabling sustained innovation initiatives (Xin, Chen, Zhang, & Sun, 2019). (3) Firm age. Established firms possess accumulated knowledge, structured processes, and mature networks that facilitate innovation (Coad, Holm, Krafft, & Quatraro, 2018; Coad, Segarra, & Teruel, 2016). (4) Firm profitability. Higher profit margins offer greater discretion to reinvest in innovation-related projects, supporting both exploratory and applied research (Audretsch, 1995; Roberts, 2001). (5) Leverage ratio. Elevated debt levels may curb innovation by increasing financial risk and diverting resources toward debt servicing rather than long-term R&D (Algieri, Aquino, & Succurro, 2020; Vermoesen, Deloof, & Laveren, 2013). (6) Total assets. A diverse asset base including tangible, intangible, and knowledge assets, enhances firms' capacity to pursue and integrate innovation (Asiaei, Bontis, Askari, Yaghoubi, & Barani, 2023; Kor & Leblebici, 2005).

(7) State ownership. State-owned enterprises (SOEs) often exhibit lower innovation output, which may be attributed to weaker market competition, bureaucratic inertia, and misaligned incentives (Jefferson, Albert, Xiaojing, & Xiaoyun, 2003).

This study utilizes a panel dataset comprising Chinese firms covering the period from 2015 to 2022. Table 2 shows the details of the regression variables in this paper. The digital economy index was constructed by the authors based on data obtained from the China Statistical Yearbook and the Peking University Digital Finance Inclusion Index. Data pertaining to firms' patent applications, R&D investment, firm size, cash flow, debt-to-asset ratio, age, profit rate, total assets, and state ownership were sourced from the CSMAR database (https://data.csmar.com/). It is anticipated that the digital economy (DIG), firm size (PEO), cash flow (CASH), leverage ratio (LEV), firm age (AGE), return on assets (ROA), and total assets will exhibit a positive association with both R&D investment (IN) and patent output (RD). Conversely, state ownership is expected to demonstrate a negative correlation with firm innovation.

Table 2. Variable description.

Variables	Description	Period	Expectation
Dependent variable			
RD	Firms' patents number each year.	2015-2022	
Mediating variable			
IN	Investment in R&D	2015-2022	+
Independent variable			
DIG	Digital economy, calculated by the author based on the entropy method.	2015-2022	
Control variables			
PEO	Firm size, represented by total firm employees (people).	2015-2022	+
CASH	Firm cash flow	2015-2022	+
AGE	Firm age, how many years has the firm been established	2015-2022	+
ROA	Firm profit rate	2015-2022	+
LEV	debt-to-asset ratio	2015-2022	+
TA	Firm total assets	2015-2022	+
SO	State ownership: whether this firm is state-owned or not; dummy variable.	2015-2022	-

5. RESULTS

5.1. Descriptive Statistics

First, descriptive statistics were computed for all variables, including means, standard deviations, minimums, and maximums. As shown in the Table 3, the total sample consists of 30,391 observations. The dependent variable RD has an average value of 2.886 with a standard deviation of 1.821, ranging from 0 to 7.188. The core explanatory variable shows a mean of 0.686, a standard deviation of 0.083, and varies between 0.601 and 1. Detailed descriptive statistics for the remaining variables are provided in Table 3.

Table 3. Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
RD	30391	2.886	1.821	0.000	7.188
DIG	30391	0.686	0.083	0.601	1.000
IN	30391	0.038	0.051	0.000	0.287
LEV	30391	0.433	0.211	0.051	0.920
Size	30391	22.319	1.379	19.695	26.602
Cash	30391	0.046	0.070	-0.174	0.249
Age	30391	2.022	0.963	0.000	3.332
ROA	30391	0.035	0.064	-0.260	0.209
PEO	30391	7.706	1.276	4.635	11.284
State	30391	0.393	0.488	0.000	1.000

5.2. Correlation Matrix

Table 4 displays the correlation matrix among all variables included in the study. A statistically significant, though modest, positive correlation is observed between the dependent variable, RD (number of enterprise patents), and DIG (digital economy development), with a correlation coefficient of 0.010*. This implies that the progression of the digital economy exerts a slight yet measurable influence on patent output. Furthermore, RD exhibits a comparatively stronger positive association with IN at 0.253*, supporting the view that heightened R&D spending corresponds to greater innovation performance.

Among the moderating and control variables, RD correlates positively with LEV (debt-to-asset ratio) at 0.034***, Size (company size) at 0.315***, and Cash (company cash flow) at 0.085***, implying that larger firms with better financial resources tend to have more patents. Moreover, RD has a notable correlation with PEO (total number of employees) at 0.437***, signifying that firms with a larger workforce are more likely to engage in patenting activities.

In contrast, a statistically significant yet modest inverse relationship is observed between State (state ownership) and RD, with a correlation coefficient of −0.020. This implies that state-owned enterprises (SOEs) may demonstrate lower patenting activity relative to their private counterparts. Meanwhile, ROA (return on assets) exhibits a positive association with RD (0.089), indicating that firms with stronger profitability are more likely to produce increased patent output. Additional notable correlations include a strong link between Size and PEO (0.734), underscoring that larger organizations generally maintain a bigger workforce. A moderate correlation between LEV and Size (0.491**) is also identified, which may reflect that firms with greater assets often operate with higher leverage.

Collectively, these correlation outcomes highlight that organizational attributes, including firm scale, financial health, and R&D engagement, serve as pivotal factors influencing patent generation. Concurrently, the development of the digital economy is also shown to exert a discernible, though limited, effect on innovation performance.

Table 4. Correlation matrix.

	RD	DIG	IN	LEV	SIZE	CASH	AGE	ROA	PEO	STATE
RD	1									
DIG	0.010*	1								
IN	0.253***	0.048***	1							
LEV	0.034***	-0.007	-0.294***	1						
Size	0.315***	-0.007	-0.194***	0.491***	1					
Cash	0.085***	-0.040***	-0.018***	-0.167***	0.071***	1				
Age	-0.026***	-0.076***	-0.219***	0.355***	0.360***	-0.021***	1			
ROA	0.089***	0.014**	-0.029***	-0.351***	0.021***	0.395***	-0.185***	1		
PEO	0.437***	-0.003	-0.128***	0.349***	0.734***	0.166***	0.232***	0.065***	1	
State	-0.020***	-0.067***	-0.262***	0.305***	0.369***	-0.031***	0.445***	-0.091***	0.264***	1

Note: * Indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

5.3. Collinearity Test

5.3.1. Multicollinearity Test

To evaluate potential multicollinearity among the explanatory variables, Variance Inflation Factor (VIF) tests were performed. The results indicate that multicollinearity does not pose a significant issue within the empirical model.

As summarized in Table 5, all variables exhibit VIF values substantially below the conventional threshold of 10, suggesting that high correlation among predictors is not present. The variables *size* and *peo* display the highest VIF values, recorded at 2.726 and 2.238 respectively, yet both remain within acceptable limits. The mean VIF across all variables is 1.593, further supporting the absence of severe multicollinearity. Additionally, all tolerance values (1/VIF) exceed 0.1, reinforcing the conclusion that the regression estimates are reliable and unaffected by collinearity.

Table 5. VIF Test Results.

	VIF	1/VIF
Size	2.726	0.367
PEO	2.238	0.447
LEV	1.753	0.57
ROA	1.419	0.704
Age	1.404	0.712
State	1.375	0.727
Cash	1.235	0.81
IN	1.171	0.854
DIG	1.012	0.988
Mean VIF	1.593	.

5.4. Regression Results

Before conducting empirical analysis, a Hausman test was performed, which rejected the null hypothesis, using a two-way fixed effects model. The Table 6 reports the influence of DIG on RD using two model specifications, both of which include industry and time fixed effects. In both models, DIG exhibits a significantly positive impact on RD; the coefficients are 0.917 and 0.695**, respectively. This indicates that enhancement in the digital economy considerably stimulates enterprises' patent output. The slightly smaller coefficient in Model (2) may reflect the inclusion of additional control variables.

Firm size shows a positive and significant association with RD in Model (2), with a coefficient of 0.433, suggesting that larger firms tend to produce more patents. In contrast, cash flow is negatively associated with patent output, showing a coefficient of -0.304**, which may imply that higher liquidity does not automatically translate into greater innovation investment.

Age (company age) negatively affects RD with a coefficient of -0.0714***, suggesting that older firms tend to have lower patenting activity, potentially due to inertia or risk aversion. Conversely, ROA (total asset profit rate) exhibits a strong positive impact (1.312***), implying that more profitable firms engage more in patenting. PEO(total number of employees) also exerts a strong positive influence (0.325***), supporting the idea that firms with a larger workforce have greater innovative capacity. State (state ownership) is positive and significant (0.103***), suggesting that state-owned enterprises demonstrate a comparatively higher propensity to engage in patent applications. The R^2 value increases from 0.360 to 0.575, illustrating that incorporating further predictors enhances the model's ability to account for variation in the outcome variable.

Table 6. Regression results.

VAR	(1)	(2)
	RD	RD
DIG	0.917*** (8.272)	0.695*** (7.670)
Size		0.433*** (43.09)
Cash		-0.304*** (-2.699)
Age		-0.0714*** (-8.180)
ROA		1.312*** (10.89)
PEO		0.325*** (33.28)
State		0.103*** (5.869)
Constant	0.516*** (3.359)	-11.06*** (-54.05)
Industry	Fixed	Fixed
Time	Fixed	Fixed
Observations	30,391	30,391
R^2	0.360	0.575

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

5.5. Robustness Test

To enhance the robustness of the empirical findings, this study adopts a dynamic panel regression methodology, employing the Generalized Method of Moments (GMM) estimator with a one-period lagged term of RD integrated into the model. Estimation outcomes, summarized in the subsequent table, demonstrate that DIG maintains a statistically significant positive correlation with RD even after controlling for the persistence of innovation performance. These results imply that the digital economy exerts a durable stimulative effect on patenting activities, thereby corroborating the reliability of the baseline regression estimates.

Additionally, a further robustness assessment was performed by substituting the dependent variable: patent grants (RD2) replaced patent applications (RD) as an alternative proxy for innovation output. The findings, likewise presented in the associated table, indicate a markedly positive association between DIG and RD2, evidenced by a coefficient of 0.714, significant at the 1% level. This stability affirms that the core conclusions are not contingent upon the specific innovation metric selected and reinforces the inference that the digital economy consistently enhances corporate innovation. Comprehensive results are available in Table 7.

Table 7. Robustness test.

Variables	(1)	(2)
	RD	RD2
L.RD	0.473*** (23.66)	
DIG	0.571** (2.129)	0.907*** (8.687)
Size	-0.00349 (-0.165)	
Cash	-0.273** (-2.134)	
Age	-0.0746*** (-5.329)	
ROA	0.600*** (4.313)	
PEO	0.388***	

Variables	(1) RD	(2) RD2
	(15.09)	
State	-0.164*** (-4.306)	
Constant	-1.283***	0.204
Time	(-3.207)	(1.409)
Industry	fixed	fixed
Time	fixed	fixed
Observations	28,692	30,391
Ar1p	0	
Hansenp	0.3711	
Ar2p	0.851	
R^2		0.372

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

5.6. Endogeneity Test

To address potential endogeneity, this study additionally employs a two-stage least squares (2SLS) instrumental variable approach, using the one-period lag of DIG (L.DIG) as an instrument. The results of this test are presented in Table 8. In the first stage, L.DIG is regressed on the current DIG to obtain fitted values. These predicted values are then used as the main explanatory variable in the second-stage regression. The results confirm a significantly positive relationship between the instrumented DIG and innovation output (RD), supporting the conclusion that endogeneity is effectively controlled and that the baseline findings remain valid.

Table 8. Endogeneity test.

Variables	(1) Phase 1 DIG	(2) Phase II RD
DIG		0.826*** (6.916)
L.DIG	0.762*** (215.6)	
Size	0.000396 (0.981)	0.431*** (41.52)
Cash	-0.00176 (-0.388)	-0.241** (-2.062)
Age	-0.000676* (-1.927)	-0.0788*** (-8.713)
ROA	0.0161*** (3.362)	1.204*** (9.766)
PEO	3.23e-05 (0.0820)	0.335*** (33.02)
State	-0.00138** (-1.974)	0.119*** (6.593)
Constant	0.164*** (19.74)	-10.38*** (-47.05)
Industry	Fixed	Fixed
Time	Fixed	Fixed
Observations	28,692	28,692
R^2	0.690	0.574

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

5.7. Mediation Effect Test

This study investigates research and development (R&D) investment (IN) as a potential mediating variable. A three-stage analytical procedure is adopted to assess the underlying mediation mechanism. Initially, the baseline regression is estimated. Subsequently, R&D investment (IN) is designated as the outcome variable and regressed against the digital economy development index (DIG). Empirical outcomes reveal a significant positive association between DIG and IN, reporting a coefficient of 0.00963. Finally, both the explanatory variable DIG and the mediating variable IN are included within a unified regression framework. Findings indicate that the coefficient for IN remains positive and statistically significant. These results imply that the advancement of the digital economy contributes to increased patent applications at the firm level, partially via promoting R&D spending. The mediation analysis further confirms that the digital economy generates a notably positive impact on corporate R&D investment, thereby fostering innovation outputs.

Table 9. Mediation effect test.

Variables	(1)	(2)
	RD	**IN**
DIG	0.695*** (7.670)	0.00963*** (3.305)
IN		
Size	0.433*** (43.09)	0.000673** (2.085)
Cash	-0.304*** (-2.699)	0.00164 (0.452)
Age	-0.0714*** (-8.180)	-0.00452*** (-16.10)
ROA	1.312*** (10.89)	-0.0433*** (-11.20)
PEO	0.325*** (33.28)	-0.00248*** (-7.905)
State	0.103*** (5.869)	-0.00426*** (-7.572)
Constant	-11.06***	0.00970
Time	(-54.05)	(1.476)
Industry	Fixed	Fixed
Time	Fixed	Fixed
Observations	30,391	30,391
R^2	0.575	0.431

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

5.8. Heterogeneity Test

This study further investigates the differential effects of the digital economy on innovation across firms by examining two key dimensions: the nature of enterprise ownership and variations among industries.

(1) Heterogeneity by ownership type. To better understand how the digital economy distinctly influences innovation in firms with different ownership structures, the sample is divided according to enterprise ownership for subgroup regression analysis (see Table 10). The results indicate that while the digital economy (DIG) exerts a positive influence on innovation across all firms, the strength of this effect varies considerably: the estimated coefficient for non-state-owned enterprises is 0.778, compared to 0.331 for state-owned enterprises. This suggests that the innovation-enhancing effect of the digital economy is more pronounced among non-state-owned firms. A possible explanation is that non-state-owned enterprises typically exhibit greater agility in decision-making and more discretion over resource allocation. These attributes may allow them to more rapidly adopt digital technologies to enhance the efficiency of R&D processes and integrate external information and knowledge, thereby boosting innovation performance. In contrast, state-owned enterprises often face more constraints in resource mobility, investment decisions, and innovation incentives, which may attenuate the marginal benefit of digital economic development on their innovation output.

(2) Analysis of enterprise heterogeneity across industries. From an industry-specific perspective, this study investigates how the digital economy influences innovation in multiple sectors, such as mining, manufacturing, production and supply of electricity/heat/gas/water, construction, wholesale and retail, real estate, health and social

work, among others (see Table 11). Empirical findings reveal that the digital economy (DIG) exerts a significantly positive influence on innovation performance in most industries. The most substantial effects are observed in health and social work (9.408*) *and wholesale and retail (2.787***), suggesting that digital transformation substantially fosters innovation in these fields. Within the manufacturing sector, the regression coefficient of DIG is 0.967***, demonstrating that digitalization markedly stimulates patent applications. Positive impacts are also identified in mining (2.601) and electricity production and supply (2.198***). Conversely, DIG exhibits a negative association with innovation output in real estate (-1.241***) and construction (-0.864*). This implies that digital progress in these industries may not directly enhance patent-based innovation, potentially due to sector-specific attributes, divergent innovation pathways, and constraints in the application scenarios for digital technologies.*

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Table 10. Heterogeneity test results.

Variables	**(1)**	**(2)**
	Non-state owned	**State-owned**
	RD	**RD**
DIG	0.778*** (7.349)	0.331* (1.959)
Constant	-9.081*** (-31.94)	-12.60*** (-41.15)
Industry	Fixed	Fixed
Time	Fixed	Fixed
Observations	18,454	11,937
R^2	0.518	0.655

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

Table 11. Regression results in different industries.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mining	Manufacturing	Electricity, heat, gas, and water production and supply industry	Construction industry	Wholesale and retail trade	Real Estate	Health and social work	Comprehensive
	RD	RD	RD	RD	RD	RD	RD	RD
DIG	2.601**	0.967***	2.198***	-0.864*	2.787***	-1.241***	9.408***	2.843**
	(2.437)	(9.416)	(3.594)	(-1.862)	(5.773)	(-2.938)	(3.038)	(2.134)
Constant	-16.52***	-11.08***	-16.24***	-13.27***	-6.335***	-3.024***	-31.19***	-6.298***
	(-13.01)	(-49.18)	(-17.62)	(-12.21)	(-7.015)	(-3.982)	(-3.852)	(-2.943)
Observations	714	19,083	1,021	775	1,588	1,199	73	236
R^2	0.624	0.531	0.525	0.762	0.236	0.215	0.642	0.495

Note: t-statistics in parentheses, * indicates p-value < 0.1, ** indicates p-value < 0.05, *** indicates p-value < 0.001.

6. CONCLUSION AND RECOMMENDATION

This study focuses on listed firms as the primary sample and employs a two-way fixed effects model combined with a mediation analysis framework to examine how the digital economy influences corporate innovation, using panel data from 2015 to 2022. The research elucidates the dynamic interactions among digital infrastructure, firm behavior, and innovation outcomes. The empirical evidence demonstrates that: (1) The digital economy exerts a substantial positive effect on corporate innovation, a conclusion that holds consistently even after accounting for variables such as firm size, profitability, cash flow, and age. This aligns with the predictions of neo-Schumpeterian economic theory, wherein shifts in technological paradigms stimulate innovation through enhanced dynamic capabilities. (2) Research and development (R&D) investment serves a significant mediating function in the relationship between digital economic development and corporate innovation. By allocating resources to digital infrastructure, platform technologies, and big data analytics, firms exhibit a greater propensity to increase R&D expenditures, thereby facilitating structural and strategic transformation and cultivating an internal environment supportive of innovation. (3) The contribution of digital economic development to corporate innovation exhibits notable heterogeneity across firms and sectors. Non-state-owned enterprises benefit more because of their flexible decision-making and strong autonomy in resource allocation; at the industry level, the health and social work, wholesale and retail, and manufacturing industries benefit the most, while innovation output appears inhibited in real estate and construction, suggesting that the effectiveness of digital transformation is constrained by industry characteristics and application scenarios.

Based on these findings. First, advance the construction of digital infrastructure to establish an enabling digital ecosystem, thereby creating a robust foundation for innovation activities within firms. Second, enhance guidance for R&D investment by utilizing fiscal subsidies, tax incentives, and directed funding to facilitate the in-depth integration of digital tools and corporate innovation processes. Third, adopt differentiated policy measures aimed at improving the financing environment and reducing institutional transaction costs for non-state-owned enterprises, while simultaneously strengthening incentive mechanisms in state-owned enterprises to accelerate digital adoption and R&D transformation. Fourth, implement targeted strategies to promote digital penetration in sectors with high digitalization potential such as manufacturing, wholesale and retail, and health services while encouraging traditionally less digitalized industries like real estate and construction to explore scenario-specific integrations of digital technologies. Fifth, refine institutional support and collaborative innovation mechanisms by fostering tripartite cooperation among government, industry, and research institutes to cultivate a synergistic ecosystem for digital and innovation-driven development.

Although this study provides an empirical analysis of the relationship between the digital economy and corporate innovation using a dataset of listed companies, several limitations should be acknowledged:

First, the sample is limited to Chinese listed firms from 2015 to 2022, which may not capture the innovation behaviors and digital practices of unlisted enterprises, thereby constraining the generalizability of the results.

Second, innovation is proxied mainly by the number of patent applications, which does not fully reflect multidimensional aspects of innovation such as quality, radicalness, or commercial success.

Third, external factors including policy support, regional institutional variations, and international digital trends were not comprehensively incorporated into the analysis.

Future research could extend this work in several directions: expanding the scope to include non-listed firms to improve external validity; introducing multidimensional innovation metrics covering quality, breakthrough technology, and market performance; and conducting cross-country or cross-regional comparative studies to examine how institutional contexts and varying stages of digital development shape innovation outcomes, thereby enhancing the theoretical relevance and practical applicability of the research.

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