The Impact of the Digital Economy on Regional Innovation: Evidence from Provincial Panel Data in China

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Abstract. Digital economy is accelerating the reshaping of regional production mode, factor allocation and innovation ecology. Whether digital economy development can be translated into stronger regional innovation capacity is crucial for evaluating the quality of digital transformation. Using panel data for 30 Chinese provinces from 2015 to 2024, this study constructs composite indices of digital economy development and regional innovation capacity through the entropy weighting method and estimates their relationship with a two-way fixed effects model. The research found that the digital economy can significantly enhance regional innovation capacity. Mechanism analyses indicate that the digital economy acts on regional innovation by influencing factor agglomeration and promoting the development of the financial industry. The moderating analysis indicates that stronger government innovation preference and greater fiscal support enhance the positive association between the digital economy and regional innovation. These findings provide empirical evidence for understanding the innovation-driven mechanisms of the digital economy.

Keywords: Digital Economy; Regional Innovation; Factor Agglomeration; Financial Industry Development; Government Innovation Support.

1 Introduction

Digitalization is reshaping where innovation resources are concentrated and how regional economies evolve. Under 14th Five-Year Plan for Digital Economy Development, core digital economy industries were expected to contribute 10% of GDP by 2025. Statistics released by the National Bureau of Statistics place the 2024 value added of China's core digital economy industries at RMB 14.09 trillion, equivalent to 10.5% of GDP. The scale of digital economy constantly expands, but whether its development can be steadily transformed into regional innovation capacity still requires empirical verification at the provincial level.

Existing research has established both direct and indirect links between the digital economy and innovation. Relevant studies find that the digital economy can not only

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promote high-quality economic development (Zhao et al., 2020), but also improve regional innovation efficiency and innovation capability (Han et al., 2019; Yang and Zheng, 2025). Relevant mechanisms of action include easing financing constraints, reducing information and transaction costs, promoting knowledge flow and improving the allocation of innovation factors (Tang et al., 2020; Yao and Bai, 2026). Although these studies provide an important foundation, the provincial roles of factor agglomeration and financial industry development, together with the conditions under which government innovation support strengthens these effects, remain insufficiently examined.

On this basis, this study focuses on three issues: the effect of digital economy development on regional innovation capacity; the mediating roles of factor agglomeration and financial industry development; and the moderating effects of government innovation preference and fiscal support.

The contributions of this study are twofold: firstly, compared with the research on urban innovation (Yang and Zheng, 2025), regional collaborative innovation (Yao and Bai, 2026) or the dynamic relationship of specific urban agglomerations (Wu et al., 2025), this paper uses panel data covering 30 provinces in China and updated to 2024 to construct comprehensive regional innovation indicators from dimensions of technological output and product innovation, which provides supplementary evidence for the provincial innovation-enhancing effect of digital economy. Secondly, in addition to bringing factor agglomeration, financial industry development and government innovation support into a unified analysis framework, this paper allows the transmission channels and boundary conditions of the digital economy's innovation effect to be examined jointly.

2 Theoretical Analysis and Research Hypothesis

2.1 Direct Mechanism of Digital Economy to Promote Regional Innovation

Regional innovation is the process by which enterprises, universities, scientific research institutions and other subjects transform knowledge, capital and talent input into new technologies and new products (Bai and Jiang, 2015). The process is easily constrained by information search cost, collaboration cost and resource allocation efficiency. The digital economy, based on modern information networks, digital technologies, and data elements, can reduce costs such as search, replication, transportation, tracing, and verification, changing the boundaries of knowledge production and market transactions (Goldfarb and Tucker, 2019). Digital technology also enhances the editability, recombinability and transferability of knowledge, which enables different subjects to collaborate through organizational and spatial constraints, thus forming a more open innovation process (Nambisan et al., 2017).

Relevant empirical studies provide support for the above judgment. Focusing on Internet development, Han et al. (2019) argued that the Internet can significantly improve the efficiency of regional innovation. An and Zhang (2021) extended the investigation object to the digital economy as a whole, and the research proves that the development of digital economy can improve the regional innovation efficiency in

China. On this basis, Yang and Zheng (2025) as well as Xu et al. (2025) proposed that the digital economy can improve regional innovation performance based on city and provincial data, respectively. Therefore, digital economy development is expected to enhance regional innovation capability by reducing the innovation cost and enhancing the efficiency of knowledge reorganization and achievement transformation. Accordingly, the following hypothesis is proposed:

H1: Regional innovation capacity increases with the development of the digital economy.

2.2 Indirect Mechanism of Digital Economy to Promote Regional Innovation

Analysis of Mediation Effect of Factor Agglomeration. The digital economy can promote the agglomeration of factors such as population and labor force in cities and areas with intensive innovation activities. Digital infrastructure and platform technology lower the costs of job searching and cross-regional labor matching, while the expansion of digital industries and the digital transformation of traditional industries create new employment and entrepreneurial opportunities, thus enhancing the attractiveness of regions to labor. It has been shown that the digital economy can weaken the administrative boundary effect and accelerate the cross-regional flow of innovative elements such as talent (Guo et al., 2023; Yang and Zheng, 2025). Population and labor agglomeration expands the regional labor market, boosts skills matching between enterprises and workers, and promotes tacit knowledge dissemination and inter-agent collaboration through personnel exchange. Meanwhile, the expansion of the local market can increase the effective use of specialized services and public innovation facilities. Therefore, the factor agglomeration induced by digital economy development can improve the matching and utilization efficiency of innovation resources and facilitate their conversion into regional innovation output. Thus, there is a hypothesis:

H2: The digital economy can enhance regional innovation capability by promoting factor agglomeration.

Analysis of Mediation Effect of Financial Industry Development. The digital economy can strengthen the financial sector. Digital technology improves information processing and risk identification through data analytics and online platforms. By reducing customer-acquisition and transaction costs, it also enables financial institutions to reach a broader range of clients (Huang and Huang, 2018). In addition, the development of financial industry can pool social funds, identify innovative projects and diversify investment risks, as well as provide external financing for innovative activities that require substantial upfront investment, involve long payback periods, and face considerable uncertainty. Zhou et al. (2017) insisted that financing constraints will affect corporate innovation capability and collaborative innovation. As a result, the development of financial industry will increase regional capital supply, improve financial services, and provide financing support for technology R&D, achievement transformation and the growth of innovative enterprises. Thus, the following hypothesis is proposed:

H3: Financial industry development mediates the positive effect of digital economy development on regional innovation capacity.

Analysis of Moderating Effect of Government Innovation Support. Innovation activities feature the long investment cycle, high failure risk and apparent knowledge spillover, etc. It is difficult for private entities to obtain all innovation benefits, which may lead to R&D investment below the social optimum. Local government science and technology expenditure can not only support digital infrastructure, public technology platforms and common technology R&D, but also reduce the fixed cost of corporate digitalization and R&D activities. Besides, a stable science and technology budget can release a signal of long-term support for innovation, attract R&D talents and financial capital, and promote cooperation between universities, scientific research institutions and enterprises. It has been shown that government support and innovation environment influence the regional innovation-enhancing effect of the digital economy (Yang and Zheng, 2025; Wu et al., 2025). Thus, the more government attaches importance to science and technology investment, the more adequate conditions for digital resources to be transformed into regional innovation output. On this basis, the following hypothesis is proposed:

H4: The government innovation preference intensity positively moderates the promotion role of digital economy on regional innovation.

H5: The government innovation preference structure positively moderates the promotion role of digital economy on regional innovation.

In addition to the budgetary priority assigned to science and technology, regional R&D investment also determines whether innovation entities can get sustained fiscal support. Although digital technology can reduce information and collaboration costs, R&D personnel compensation, experimental equipment, trial production and achievement transformation still require substantial upfront investment, and financing constraints may make it difficult for enterprises to turn digital opportunities into innovative activities. Studies have found that government R&D funding can drive corporate R&D expenditure, alleviate financing constraints on early-stage projects, and promote innovation (Xie et al., 2009; Howell, 2017). The more adequate R&D funding is invested, the easier the role of digital technology in reducing costs, improving matching and promoting collaboration is to be transformed into innovative output, and the stronger the marginal promotion role of digital economy on regional innovation. On this basis, there is a following hypothesis:

H6: The fiscal support intensity positively moderates the promotion role of digital economy on regional innovation.

3 Study Design

3.1 Model Setting

Baseline Regression Model. To test H1 and explore the direct effect of digital economy on regional innovation, the following baseline panel regression model is constructed:

$$Innov_{it} = \alpha + \beta \cdot Dige_{i,t-1} + \gamma \cdot Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where $Innov_{it}$ indicates the regional innovation capability of province i in the t-th year; $Dige_{i,t-1}$ is the digital economic development of province i in the t-1 year; $Controls_{it}$ denotes a set of control variables; μ_i is the provincial fixed effect; λ_t is the year fixed effect; ε_{it} is the random error term. Standard errors are clustered at the provincial level.

Mediation Effect Model. To test H2 and H3, this paper adopts a stepwise regression based on the baseline model (Baron and Kenny, 1986). The baseline model formula (1) estimates the total effect between the digital economy and regional innovation, followed by the equations below, respectively:

$$M_{it} = \alpha_1 + aDige_{i,t-1} + \gamma_1 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$Innov_{it} = \alpha_2 + c'Dige_{i,t-1} + bM_{it} + \gamma_2 Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

Where M_{it} refers to the mediator variable; coefficient a reflects the effect of digital economy development on the mediator; coefficient b captures the association between the mediator and regional innovation conditional on digital economy development; a×b refers to the corresponding indirect effect.

Moderating Effect Test Model. To test H4, H5, and H6, this paper takes government innovation preference intensity, government innovation preference structure, and fiscal support intensity as moderating variables, respectively. Moreover, moderating variables and their interaction terms with digital economy are added to the benchmark model:

$$Innov_{it} = \alpha + \beta_1 Dige_{i,t-1} + \beta_2 Mod_{it} + \beta_3 (Dige_{i,t-1} \times Mod_{it}) + \gamma Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Where Mod_{it} is the moderating variable; $Dige_{i,t-1} \times Mod_{it}$ is the interaction term after centralization. β_3 captures how the estimated effect of digital economy development changes with the moderator. A significantly positive β_3 indicates that a higher level of the corresponding moderator strengthens the positive relationship between digital economy development and regional innovation.

3.2 Variable Definition and Measurement

Explained Variable: Regional Innovation Capacity (Innov). Regional innovation capacity is measured from the perspective of innovation output. Based on the comprehensive measurement of related research (Yang and Zheng, 2025; Wu et al., 2025), the entropy weighting method is applied to combine the number of patent grants and the sales revenue of new products of industrial enterprises above designated size into a regional innovation capacity index (Innov). The resulting index captures both technological output and the commercialization of innovation outcomes. To facilitate the interpretation of the regression coefficient, this paper multiplies the comprehensive index of regional innovation capacity by 100.

Explanatory Variable: Digital Economy Development (Dige). According to the research of Zhao et al. (2020), this study uses entropy weights to combine five dimensions into a composite index of digital economy development (Dige): Internet penetration rate, number of Internet-related employees, Internet-related output, number of mobile Internet users and digital inclusive finance development. To facilitate the interpretation of the regression coefficient, this paper multiplies the calculated comprehensive index of digital economy development by 100. Given that the effect of digital economy development on regional innovation may have time-lag effect, the development of digital economy lagging one period ($Dige_{i,\,t-1}$) is adopted as the core explanatory variable in the baseline model. The construction of the specific index system is shown in Table 1.

Mediating Variables. To examine the transmission channels linking digital economy development to regional innovation, two mediators are considered: factor agglomeration and financial industry development. One is factor agglomeration (FA). It is measured as the share of the urban population in the year-end permanent resident population. Higher values indicate a greater degree of population and labor force agglomeration in urban space. The other is financial industry development (FinDev). It is measured as the natural logarithm of value added in the regional financial sector.

Moderating Variables. This paper sets up the moderating variables from three aspects: the investment intensity of government financial expenditure, the priority of budget and the base of regional R&D investment. Government innovation preference intensity (GI) is defined as local science and technology expenditure relative to regional GDP, reflecting the scale of such expenditure relative to the regional economy. Meanwhile, government innovation preference structure (GS) represents the share of science and technology spending in general public budget expenditure and therefore indicates its priority within local fiscal allocation. In addition, fiscal support intensity (FS) is measured by the natural logarithm of the internal expenditure of R&D funding, reflecting the base of funding input received by regional R&D activities.

Control Variables. To control the impact of industrial structure and economic development on regional innovation, there are following control variables in this paper: industrial development (IndRatio), service development (SerRatio) and economic development (EcoRatio), which are measured by the ratio of secondary industry added value to regional GDP, tertiary industry added value to regional GDP and natural logarithm of per capita regional GDP, respectively.

3.3 Data Source and Sample Selection

The analysis uses Chinese provincial panel data from 2015 to 2024, collected from the China Statistical Yearbook, the China Statistical Yearbook on Science and Technology, the China Statistical Yearbook on High-tech Industry, the China Labor Statistical Yearbook, the China Financial Statistical Yearbook, and the Peking University Digital Financial Inclusion Index. As for sample processing, Tibet Autonomous Region is excluded because several key variables are seriously missing. The final sample consists of 300 province-year observations from 30 provinces. For the missing observations, they were supplemented using official statistical bulletins or linear interpolation methods. Table 2 shows descriptive statistical results for variables.

Table 1. Indicator System of Comprehensive Development of Digital Economy

First-Level Indicator	Second-Level Indicator	Third-Level Indicator
Digital Economy Development	Internet Penetration Rate	Number of Internet Users Per 100 People
	Number of Internet-related Employees	Information Transmission, Software and Information Technology Services Percentage of Employees
	Internet Related Outputs	Total Telecommunications Business Volume Per Capita
	Number of Mobile Internet Users	Number of Mobile Phone Users Per 100 People
	Development of Digital Inclusive Finance	China Digital Inclusive Finance Index

Table 2. Descriptive Statistics of Main Variables

Variable	Variable Definition	Observations	Mean	Standard Deviation	Minimum	Maximum
Innov	Regional Innovation Capacity	300	12.924	17.846	0.145	87.382
Dige	Digital Economy Development	300	20.598	13.181	3.237	63.223

FA	Factor Agglomeration	300	0.631	0.108	0.400	0.942
FinDev	Financial Industry Development	300	7.474	0.902	5.337	9.425
GI	Government Innovation Preference Intensity	300	0.005	0.003	0.002	0.017
GS	Government Innovation Preference Structure	300	0.024	0.016	0.005	0.066
FS	Fiscal Support Intensity	300	10.593	1.318	7.056	12.993
IndRatio	Industrial Development	300	0.376	0.075	0.159	0.503
SerRatio	Service Industry Development	300	0.528	0.087	0.390	0.848
EcoRatio	Economic Development	300	11.089	0.428	10.280	12.182

4 Empirical Results

4.1 Baseline Regression Results

Table 3 reports the baseline regression results. In Column (1), without control variables, province fixed effects, or year fixed effects, the coefficient on digital economy development is 0.299 and is statistically significant at the 5% level. Column (2) uses the digital economy development lagging one period, and adds control variables, while controlling the province fixed effect and the year fixed effect. The results indicate that the coefficient on lagged digital economy development is 0.053 and remains statistically significant at the 5% level. Taken together, the estimates consistently associate stronger digital economy development with higher regional innovation capacity, providing support for H1.

Table 3. Baseline Regression Results

Variable	(1)	(2)
Dige	0.299**	
	(0.136)	
$Dige_{i, t-1}$		0.053**
		(0.025)
IndRatio		-15.743
		(21.843)
SerRatio		20.088
		(22.253)
EcoRatio		15.373***
		(3.824)
Province Fixed Effect	NO	YES
Year Fixed Effect	NO	YES
Observations	300	270
R^2	0.045	0.320

Note: Values in parentheses are standard errors clustered by province. Significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

4.2 Mechanism Test Results

Table 4 further examines the two transmission paths of factor agglomeration and financial industry development. Column (1) reports the total effects in the baseline model as a reference for mechanism testing. Columns (2) and (3) examine the feature aggregation path. Column (2) indicates that the coefficient on lagged digital economy development in the factor agglomeration equation is 0.0002, which is significant at 10%. Thus, the development of digital economy contributes to the spatial concentration of population and labor in urban areas. According to Column (3), after adding factor agglomeration to the baseline model, the coefficient of factor agglomeration is 76.174, and it is significant at the level of 10%, indicating that factor agglomeration is significantly correlated with the improvement of regional innovation capability, and the coefficient of digital economy decreases from 0.053 to 0.035, but it is still significant at 10%. The above results show that the digital economy can directly promote regional innovation, and indirectly act on regional innovation by increasing the factor agglomeration. Thus, H2 is supported.

Columns (4) and (5) examine the development path of the financial industry. Column (4) indicates that the coefficient on lagged digital economy development in the financial industry development equation is 0.002 and is statistically significant at the 1% level. These results suggest that digital economy development promotes financial industry development. After financial industry development is added to the innovation equation in Column (5), its coefficient is 19.875 and is statistically significant at the 5% level. The coefficient on lagged digital economy development decreases from 0.053 in Column (1) to 0.009 in Column (5). This pattern suggests that the digital economy enhances regional innovation partly by supporting financial industry development and expanding the capital and financial resources available for innovation. Thus, H3 is supported.

Table 4. Mediation Tests for Factor Agglomeration and Financial Industry Development

Variable	(1) Innov	(2) FA	(3) Innov	(4) FinDev	(5) Innov
$Dige_{i,\,t-1}$	0.053**	0.0002*	0.035*	0.002***	0.009
	(0.025)	(0.0001)	(0.019)	(0.001)	(0.018)
FA			76.174*		
			(41.826)		
FinDev					19.875**
					(7.414)
Control Variables	YES	YES	YES	YES	YES
Province Fixed Effect	YES	YES	YES	YES	YES
Year Fixed Effect	YES	YES	YES	YES	YES
Observations	270	270	270	270	270
R^2(within)	0.320	0.696	0.379	0.746	0.404

Note: Values in parentheses are standard errors clustered by province. Significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

4.3 Results of Moderating Effect Test

Table 5 reports the results of the moderating effect test. In Column (1), the coefficient on the interaction between digital economy development and government innovation preference intensity is 28.117, which is significant at 5%. In Column (2), the coefficient on the interaction between digital economy development and government innovation preference structure is 7.019, which is significant at 5%. The positive interaction estimates imply that digital development generates larger innovation gains where science and technology spending is both more substantial relative to the regional economy and more highly prioritized in local budgets. H4 and H5 are supported. Column (3) examines the moderating role of fiscal support intensity. The coefficient on the interaction between digital economy development and fiscal support intensity is 0.107 and is statistically significant at the 1% level. This result indicates that a stronger regional R&D funding base amplifies the positive association between digital economy development and regional innovation capacity. As a result, H6 is supported.

Table 5. Results of Moderating Effect Test

Variable	(1) GI	(2) GS	(3) FS
$Dige_{i,\,t-1}$	0.050**	0.055**	0.068**
	(0.020)	(0.025)	(0.029)
GI	773.660*		
	(430.121)		
$Dige_{i,\,t-1} \times GI$	28.117**		
	(11.176)		
GS		129.780	
		(166.817)	
$Dige_{i,\,t-1} \times GS$		7.019**	
		(2.871)	
FS			5.185
			(5.526)
$Dige_{i,\,t-1} \times FS$			0.107***
			(0.032)
Control Variables	YES	YES	YES
Province Fixed Effect	YES	YES	YES
Year Fixed Effect	YES	YES	YES
Observations	270	270	270
R^2	0.374	0.362	0.383

Note: Values in parentheses are standard errors clustered by province. Significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively. All interaction term variables were centralized. A positive interaction term coefficient indicates that the corresponding moderating variables enhance the positive relationship between digital economy and regional innovation.

5 Robustness Test

Table 6 summarizes three alternative specifications used to determine whether the baseline result depends on the original variable and model settings. First, replace the explained variable. Column (1) uses the natural logarithm of patent grants as an alternative dependent variable. The results show that the coefficient on lagged digital economy development is 0.015 and is statistically significant at the 1% level. Second, exclude municipalities directly under the central government. Column (2) re-estimates the model after excluding Beijing, Tianjin, Shanghai, and Chongqing. The coefficient on lagged digital economy development is 0.058 and is statistically significant at the 10% level. Third, the first-order difference model is adopted. Column (3) re-estimates the model using first-difference specifications of the main variables, thereby removing time-invariant provincial heterogeneity. The coefficient on the change in digital economy development is 0.038 and is statistically significant at the 1% level. Taken together, the three checks provide consistent support for the robustness of the baseline finding.

Table 6. Robustness Test

Variable	(1) Alternative Dependent Variable: lnPatent	(2) Exclude Municipalities	(3) First-Difference Model
$Dige_{i,t-1}$	0.015***	0.058*	
	(0.001)	(0.030)	
$\Delta Dige_{i,t-1}$			0.038***
			(0.013)
Control Variables	YES	YES	YES
Province Fixed Effect	YES	YES	YES
Year Fixed Effect	YES	YES	YES
Observations	270	234	240
R^2	0.749	0.309	0.032

Note: Values in parentheses are standard errors clustered by province. Significance at the 1%, 5%, and 10% levels is denoted by ***, **, and *, respectively.

6 Conclusions and Policy

6.1 Research Conclusions

First, provincial innovation capacity improves with digital economy development. This relationship persists when the dependent variable is changed, the four centrally administered municipalities are removed, and the main variables are estimated in first differences.

Second, factor agglomeration and financial industry development are important channels through which digital economy development affects regional innovation. By

encouraging population and labor agglomeration, the digital economy improves the matching of innovation factors; by supporting financial industry development, it expands the funding available for innovation activities.

Third, government innovation support strengthens the positive effect of digital economy development on regional innovation capacity. Greater local government expenditure on science and technology, higher budgetary priority for such expenditure, and a stronger regional R&D funding base all improve the conversion of digital economy development into regional innovation outcomes.

6.2 Policy Recommendations

First, policy priorities should shift from expanding the scale of the digital economy to strengthening its innovation conversion capacity. The empirical results show that digital economy development has a robust positive effect on regional innovation capacity. While improving digital infrastructure, local governments should promote the application of digital technology in R&D and design, technology transaction and achievement transformation, and promote the connection between data platforms, public technology service platforms and enterprise innovation activities. For areas with weak digital economy foundation, we should focus on improving network infrastructure, digital talent supply and digital application capabilities of enterprises.

Second, the digital economy should be used to guide the orderly agglomeration of population and labor. Local governments should rely on the development of digital industries and the digital upgrading of traditional industries to expand high-quality employment space, improve the employment information sharing mechanism, vocational skills training system and talent service platform, and promote the matching efficiency of labor supply and demand. Meanwhile, the carrying capacity of public services such as education, medical care, housing and public transportation should be enhanced. The coordination of population agglomeration with industrial development, urban governance and innovative resource layout should be promoted.

Third, we should enhance the financial industry's ability to serve the real economy and technological innovation. Local governments should facilitate the digital upgrading of financial institutions. More accurate borrower screening and project-risk assessment can help direct credit resources toward technology-oriented SMEs, start-ups, and R&D projects with long investment horizons. At the same time, risk-sharing and information-sharing mechanisms for technology finance should be improved to direct more financial resources toward innovation actors with genuine R&D needs and growth potential.

Fourth, the allocation efficiency of government science and technology expenditure should be improved. Local governments should promote the project selection, performance evaluation and withdrawal mechanism of science and technology expenditure, give priority to supporting projects with knowledge spillover, public platform and early R&D attributes, and reduce duplication of construction and continuous subsidies to inefficient entities. For areas with weak R&D foundation, the synergy between financial funds and social capital, financial institutions and enterprises should be

consolidated, so that such coordination can help build a sustainable innovation investment system and support the innovation effects of digital economy development.

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