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Original Paper

Research on the Impact of Innovation Factor Agglomeration on the Development of Provincial Digital Economy

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Abstract

In the context of the rapid development of digital China, data has become a key element of production, and new generation technologies such as artificial intelligence and computing networks have accelerated integration and innovation. However, there is a significant "provincial gap" in the development of our country's digital economy, and the gap between the east coast and the inland in the central and western regions is obvious, which is closely related to the spatial imbalance of innovation elements such as high-end talents, R&D capital, key technologies and data resources. Therefore, this paper selects 30 provinces in China (Tibet region, Hong Kong region, Macao region and Taiwan region are not included in the statistics due to serious lack of data) as the research objects, and uses entropy to synthesize the aggregation level (Ino) of innovation factors in 30 provinces from 2011 to 2022, covering three dimensions: talent, technology and capital. From the perspectives of digital infrastructure, digital industry development and digital financial inclusion, the comprehensive value (De) of the digital development level of each region from 2011 to 2022 is obtained, and control variables such as technology market development, urbanization level, government intervention, openness, employment density and regional financial development intensity are included, and the two-way fixed effect is selected as the benchmark regression model. Finally, through empirical research, the aggregation of innovation factors can significantly promote the development of the regional digital economy, and the robustness test of innovation factor aggregation has been postponed for a period of time, and the positive promotion results are still significantly improved, and finally the corresponding policy conclusions are given.

Keywords

Innovation factor agglomeration, digital economy development, entropy method, two-way fixed effect model, lagging first phase test

1. Introduction

We are in a new era where digital technologies are redefining the paradigm of global economic growth. As the main economic form after the agricultural economy and industrial economy, the development level of the digital economy has become a key criterion for measuring the core competitiveness and future potential of a country or region. According to the “White Paper on the Global Digital Economy” released by the China Academy of Information and Communications Technology, the scale of the global digital economy will exceed $55 trillion in 2023, accounting for more than 46% of GDP, and the growth rate will far exceed that of traditional economies. Bo et al. (2025) believe that the integration and development of digital technology represented by big data, mobile Internet, cloud computing, etc. and traditional industries has promoted the improvement of resource utilization and allocation, and the innovation of traditional industries has also experienced major butterfly-like changes driven by the digital economy.In addition, the establishment and widespread use of digital platforms also have a positive impact on innovation efficiency. In this magnificent wave of change, a sobering phenomenon is that the growth of the digital economy is not evenly distributed in geographical space, but presents significant or even intensified spatial aggregation characteristics. From Silicon Valley in the United States to the Yangtze River Delta in China, these regions are like powerful magnetic poles, continuing to attract core innovation elements such as talent, capital, technology and data, giving birth to a more active digital industry ecology and higher productivity. Since Marshall proposed the theory of industrial zones, the theory of new economic geography and innovation systems has elaborated in depth the classic factor aggregation mechanism to improve economic efficiency through knowledge spillover, professional labor pool and intermediate input sharing. However, the rise of the digital economy has injected new subversive meanings into this traditional proposition. First, the factors of production themselves have undergone fundamental changes. Data and information have replaced traditional material resources and become the most critical new factor of production. Digital platforms break the shackles of geographical distance and create a new form of virtual aggregation; Algorithms and computing power form the new infrastructure. This makes the assumptions about transportation costs and geographic proximity in traditional aggregation theories need to be revisited. Second, the drive mechanism is more complex and diverse. In the digital economy, agglomeration not only promotes the diffusion of explicit knowledge, but also accelerates the flow and reorganization of tacit knowledge and digital creativity through open source communities, collaborative research and development on the cloud, and platform ecological interaction. In addition, digital technology has also profoundly changed the geographical scale of agglomeration, which may form close innovation clusters locally and network collaboration globally. Based on existing studies, a large number of studies have affirmed the promotion effect of agglomeration on the digital economy, but most of them focus on macro description or analysis of single elements (such as venture capital), and lack of systematic deconstruction of the multi-dimensional innovation element package and its synergistic effects of “talent-capital-technology-data”. In this context, this study aims to penetrate the appearance and

systematically analyze the transmission mechanism of innovation factor agglomeration affecting the development of digital economy. This can provide a crucial decision-making basis for regions and countries that are actively deploying innovation networks, building a digital China, and promoting common prosperity. It not only helps to explain the current geographical imbalance pattern of digital economy growth, but also allows policymakers to design effective innovation and regional policies, guide the orderly flow and efficient allocation of innovation elements, so as to maximize the growth potential of the digital economy and provide solid theoretical support and empirical reference.

2. Research Hypotheses

According to the theory of endogenous growth, sustained economic growth comes from knowledge accumulation, technological progress and human capital improvement, which are the core connotations of innovation elements. As an emerging economic form, the development of the digital economy is by no means a source of water. Every leap forward - from PC Internet to mobile Internet to artificial intelligence and industrial Internet - directly depends on collective breakthroughs in underlying technologies (such as mobile chips, high-speed networks, intelligent algorithms) and innovative organizations and talents that transform these technologies into business value. Without continuous investment in innovation factors, the digital economy will remain in simple model replication and scale expansion, and will not be able to achieve qualitative climbing. Li et al. (2024) pointed out that the agglomeration of innovation elements refers to the phenomenon of spatial agglomeration in which key innovation resources such as technology, talent, and capital are concentrated and gathered in a specific region. Ye (2025) pointed out that the aggregation of talent innovation elements effectively makes up for the talent gap in key links of the industrial chain, improves the adaptability and anti-risk ability of the industrial chain, and enhances the resilience of the digital economy industry chain. The agglomeration of technological innovation elements will help enhance the interactive circulation of the internal and external chains of the digital economy industry chain, promote the iterative upgrading of industrial chain production technology, enhance the independent and controllable ability of the industrial chain, ensure the stability and security of the industrial chain, and then forge the resilience of the digital economy industry chain. The agglomeration of capital innovation elements can provide diversified financing and exit channels for the production and operation of the digital economy industry chain, increase industrial mergers and acquisitions, provide necessary financial support for the research and development of high-tech projects of enterprises, and promote the resilience of the digital economy industry chain. Ge (2024) believes that the core of the development of the digital economy is digital technology, and digital technology itself is the product of innovation and development, so the process of digital economy development is also a process of technological progress and improvement of innovation capabilities.The agglomeration of innovation elements drives the development of the digital economy through a “systemic multiplier effect”. At its core, the high-density convergence of talent, capital, technology, and data in specific spaces (such as Silicon Valley) is not simply superimposed, but

rather builds an efficient innovation ecosystem by accelerating knowledge spillover and restructuring, spawning specialized markets, and strengthening collaborative trust networks. This system not only directly incubates new formats such as artificial intelligence and big data (digital industrialization), but also acts as a key enabler to comprehensively improve the efficiency and model of traditional industries (industrial digitalization). Ultimately, this agglomeration significantly reduces the innovation costs and risks of the whole society, accelerates technology iteration and commercial application, and is the fundamental driving force for shaping the disruptive productivity and new economic geographical pattern in the digital economy era. Therefore, this paper proposes research hypotheses:

The agglomeration of innovation elements has a positive effect on the development of the provincial digital economy.

3. Research Design

Referring to the approach of Xu (2025), the agglomeration of innovation elements is comprehensively measured from three dimensions: technological innovation factor agglomeration, talent innovation element agglomeration, and capital innovation factor agglomeration, and the comprehensive value (Ino) of innovation factor agglomeration in each province from 2011 to 2022 is obtained by using the entropy method as the core explanatory variable. Refer to the ideas of Guo et al. (2020), this paper constructs a comprehensive index system for the evaluation of digital economy development from three perspectives: digital infrastructure, digital industry development and digital inclusive finance, and uses the entropy method to obtain the comprehensive value (De) of digital development level in each region from 2011 to 2022, which is taken as the core explanatory variable. In order to control the individual characteristics that do not change with time (such as regional culture and initial conditions) and the time trend that does not change with individuals (such as macroeconomic shocks and general technology diffusion), so as to more accurately identify the net causal effect of innovation factor agglomeration on the digital economy, the two-way fixed effect model is selected as the benchmark regression model. In order to eliminate the influence of other factors, the degree of technology market development, urbanization level, government intervention, degree of opening up, employment density and regional financial development intensity are selected as control variables. The baseline regression model is as follows:

$$De_{it} = \alpha_0 + \alpha_1 \ Ino_{it} + \alpha_2 Control\_Var_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

In the above equation, Deit is the explained variable, which represents the level of digital economy development in province i in year t, and Ino it is the core explanatory variable, which represents the agglomeration level of innovation elements in province i in year t, and Control_Varit is the control variable, including the degree of technology market development, urbanization level, government intervention, degree of opening up, employment density and regional financial development intensity, α0, α1 and α2 are the regression coefficients of constant terms, core explanatory variables and control

variables, respectively. μi represents the province fixed-effect dummy variable, φt represents the year fixed-effect dummy variable, and εit represents the random perturbation term.

4. Empirical Analysis

4.1 Descriptive Stats

In the table below, the observation sample is 360 sets of data from 30 provinces and autonomous regions from 2011 to 2022, of which the maximum value of the core explanatory variable (Ino) is 0.8158, the minimum value is 0.0146, the mean value is 0.162, and the standard deviation is 0.134. Moreover, the degree of innovation factor agglomeration in most provinces is generally low (the mean of 0.162 is far lower than the possible median), and the data show a significant right-biased distribution (mean 0.162 + standard deviation of 0.134 is close to the maximum range). The maximum value of the core explanatory variable (De) is 0.7120, the minimum value is 0.0170, the mean is 0.145, and the standard deviation is 0.117, while the descriptive statistic of the core explanatory variable (De)—extremely heterogeneous distribution, low overall level, and significant right-bias—is almost completely synchronized with the features of the core explanatory variable (Ino), which proves a strong linear fitting relationship between the two.

Table 1. Results of Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Ino	360	0.162	0.134	0.0146	0.8158
De	360	0.145	0.117	0.0170	0.7120
Ope	360	0.137	0.133	0.0041	0.6768
Urb	360	0.600	0.122	0.3503	0.9377
Stop	360	0.018	0.030	0.0002	0.1910
Gov	360	0.259	0.111	0.1050	0.7583
Jde	360	0.257	0.271	0.0044	0.2171
Fdl	360	0.026	0.038	1.6879	7.6178

4.2 Analysis of the Trend of Changes in Core Variable

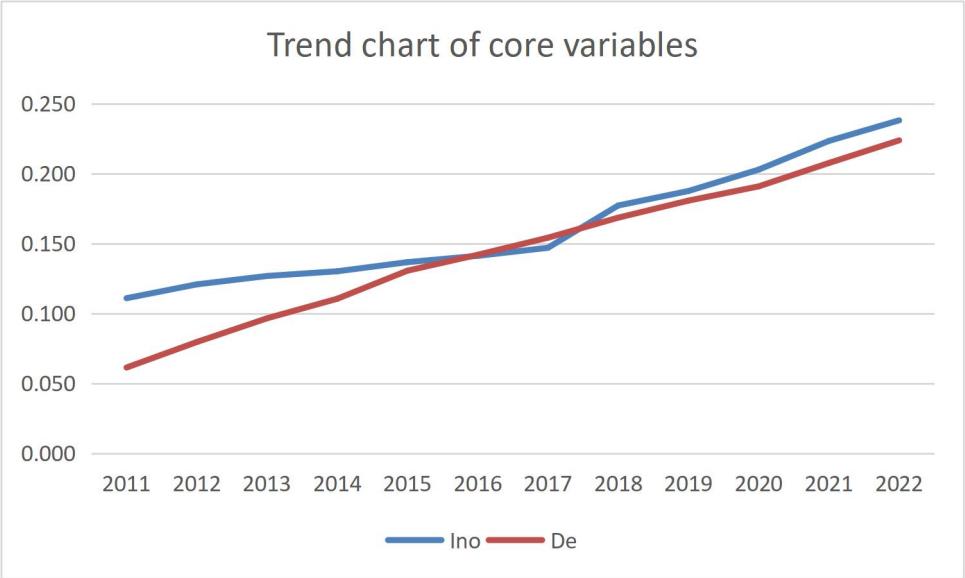

Figure 1. Trend Chart of Core Variables

The continuous agglomeration and structural upgrading of innovation elements are the fundamental and dominant reasons driving the development of the digital economy from germination, outbreak to deepening, rather than just accompanying phenomena or passive results. This judgment is rooted in the essential attributes of innovation and the inherent laws that play a role in the economic system. First of all, from the perspective of theoretical mechanism, the innovation elements with talent, capital, technology and data as the core constitute the original core of the productivity of the digital economy. Every leapfrog development of the digital economy – whether it is the migration from the PC Internet to the mobile Internet, or the penetration from consumer interconnection to industrial intelligence – is directly derived from the collective breakthroughs of the underlying technology (such as mobile chips, distributed computing, deep learning algorithms) and the organizational ability to translate these breakthroughs into market value. The accumulation of these technologies and capabilities is by no means the product of the spontaneous growth of the market, but the result of long-term and targeted investment and agglomeration of innovation elements. For example, the rise of the artificial intelligence industry first relies on the convergence of the world's top algorithm talents to specific enterprises or regions, the construction of large-scale high-quality data sets, and the capital support focused on long-term investment, and then gives birth to a series of new digital economy formats such as intelligent recommendation, autonomous driving, and industrial quality inspection, thereby improving the overall De indicator. Secondly, from the perspective of time, innovation activities have a natural time lag effect. R&D investment, talent training, technology exploration to finally commercialization and economies of scale impact require a complete cycle. The fact that Ino can still significantly promote De after a period of lag is an empirical capture of this cycle: it shows that the

innovation reserve in the early stage is a "pre-investment" to inject momentum into the subsequent growth of the digital economy. This means that when we observe the current boom in the digital economy, its engine has been started as early as the past one or several cycles. This finding not only reinforces the direction of causality (it is the past Ino that drives the current De, not the other way around), but also reveals that the forward-looking of policy and strategy is crucial: today's investment in basic research, high-end talents and key technologies determines the competitiveness and height of tomorrow's digital economy. Furthermore, this causal relationship is characterized by path dependence and self-reinforcement. After the early innovation elements successfully gather and give birth to breakthroughs in a certain field of the digital economy (such as China's mobile payment), they will form a strong demonstration effect and ecosystem, attracting more innovative elements in related fields (such as security technology, blockchain, and cross-border payment talents) to further pour in, thereby driving the evolution of the digital economy to a more complex and higher value-added form. Therefore, the agglomeration of innovation elements is not only the "igniter" of the development of the digital economy, but also the "accelerator" of its continuous upgrading. To sum up, the vigorous development of the digital economy is regarded as a towering tree, then the agglomeration of innovation elements is deeply rooted in the root system of the soil and the stem that transports nutrients. Sunshine and rain (market demand, policy environment) are important, but whether they can grow and the growth form are ultimately determined by whether the root system is developed and whether the stem is strong. Therefore, the strategic core aimed at promoting the high-quality development of the digital economy must unswervingly return to building a more attractive and productive innovation ecology, and continue to optimize the talent structure, smooth capital channels, encourage technological originality, and release the value of data through systematic institutional arrangements, so as to firmly grasp the fundamental initiative to drive future economic development.

4.3 Benchmark Regression Analysis

Table 2. Baseline Regression Results

	(1)
	de
Ino	0.757***
	(0.020)
Ope	-0.174***
	(0.026)
Urb	-0.223***
	(0.045)
Stop	-0.421***
	(0.099)

Gov	-0.087**
	(0.036)
Jde	-0.416*
	(0.216)
Fdl	0.004
	(0.003)
_cons	0.149***
	(0.025)
N	360
R2	0.966

The above table shows that using the two-way fixed effect model, after controlling for time and individual effects, the agglomeration of innovation elements has a positive effect on the development of the provincial digital economy. Specifically,. The regression coefficient of the core explanatory variable innovation element agglomeration level (INO) was 0.757, which was highly significant at the statistical level of 1% (P<0.01). This result shows that for every 1 unit of innovation factor agglomeration level under the control of other variables, the level of digital economy development will be significantly increased by about 0.757 units, which strongly supports the core assumption that "innovation is the core driving force of digital economy development". At the same time, the influence of other control variables is structural. The estimated coefficients of opening up to the outside world (OPE), urbanization level (URB), technology market development degree (STOP), government intervention degree (GOV) and employment density (JDE) are all negative, and the significance tests of 1%, 1%, 1%, 5% and 10% statistical levels are passed respectively. These significant negative relationships may imply that: first, in the current development stage, there may be a certain resource competition or structural mismatch between the export-oriented economy or the traditional urbanization model in some regions and the endogenous innovation and development path of the digital economy; Second, the marginal effect of the existing forms of technology market development, government intervention and employment density may have entered a period of adjustment, and its traditional way of pulling the digital economy is changing or needs to be optimized. The coefficient of financial development level (FDL) has not passed the significance test, indicating that its direct impact on the development of the digital economy under the setting of this model is still unclear. The overall goodness of fit (R^2) of the model is 0.966, indicating that the explanatory variable has a very strong explanatory power for the change of the interpreted variable. In summary, the empirical results not only confirm that the agglomeration of innovation elements have a fundamental positive promotion effect, but also reveal the complex nonlinear or phased relationship between other socio-economic variables and the digital economy, which provides an important basis for in-depth discussion of structural transformation and policy optimization.

4.4 Robustness Analysis

Table 3. Robustness Regression Results

	(1)
	de
L.ino	0.788***
	(0.023)
ope	-0.199***
	(0.030)
urb	-0.224***
	(0.049)
stop	-0.125
	(0.106)
gov	-0.024
	(0.039)
jde	-0.445
	(0.289)
fdl	-0.003
	(0.004)
_cons	0.174***
	(0.027)
N	330
R2	0.959

In the robustness test, the innovation factor agglomeration (Ino) still maintains a significant positive promotion of the development of the digital economy (De) after lagging one period, and the promotion effect is stronger - every 1 unit of innovation factor agglomeration will cause the level of digital economy development to increase by 0.788 units. This provides key evidence for the causal relationship of "innovation-driven development" from an econometric point of view. Its core logic is to profoundly reflect the "time lag effect" that inevitably exists when innovation plays a role. Input to innovation – whether it's R&D funding, high-end talent introduction, or knowledge of new technologies – is not instantly translated into economic output like a fuel injection engine. It must go through a complex "transformation-diffusion-absorption" cycle: from technology research and development, product development to market adoption and large-scale application, the entire process takes time. For example, a large investment in an AI lab or the introduction of a top team may take the next year or even later to form a commercially viable solution and penetrate the industry, driving up digital economy indicators. Therefore, the significant positive effect of the lagging period just captures

and confirms this objective economic process, indicating that the current innovation agglomeration is an advance investment for the future digital economy. At the same time, this test result also effectively excludes the interference of reverse causality - that is, it is not the prosperity of the current digital economy that instantly attracts innovation elements, but the early innovation accumulation drives the current economic development, which makes the direction of causality clearer and more credible. It also reminds policymakers that policies that promote innovation have delayed economic effects, and that they need to be patient in evaluating them with a focus on long-term rather than immediate returns.

5. Conclusion

In terms of empirical evidence, in order to eliminate the interference caused by time and individual effects, the two-way fixed effect model is used for benchmark regression, and the interference of other variables is considered, and six control variables of technology market development, urbanization level, government intervention, degree of opening up, employment density and regional financial development intensity are included in the model for regression. Finally, it is concluded that the agglomeration of innovation elements has a significant positive effect on the development of the provincial digital economy. This finding is confirmed by the typical fact that “innovation factors and digital economy levels are highly synchronized in distribution, and a few high-level units and a large number of low-level units coexist” observed in descriptive statistics, which jointly reveal the key dynamic mechanism of regional digital economy development. Therefore, policy formulation should attach great importance to the cultivation and agglomeration of innovation elements, and regard it as the core strategic fulcrum to enhance digital competitiveness and cross the development threshold.

Based on the three-dimensional research conclusion of “talent-capital-technology”, in order to promote the high-quality development of the provincial digital economy, policy formulation needs to build a differentiated, collaborative and ecological precise support system, the core of which is to transform the static agglomeration advantages of elements into dynamic innovation advantages and industrial competitiveness. First, implement a hierarchical and full-cycle talent strategy. For leading provinces with a high concentration of innovation elements (such as the eastern coastal areas above the mean), the policy focus should shift to building a global talent highland, and attract and retain strategic scientists and architects who can break through the “bottleneck” technology through platforms such as international joint laboratories and top scientist studios. For provinces in the early stage of agglomeration, efforts should be made to cultivate localized and application-oriented digital talents, consolidate the human capital foundation of digital transformation through the “industry-education integration community”, order-based training and large-scale vocational skills improvement plans, and build a high-quality living circle to enhance talent stickiness. Second, create a capital support system with strong guidance and risk-sharing. We should go beyond simple financial subsidies and build a relay financing ecology of “government guidance funds, market-oriented venture capital, bank technology credit, and capital market”. Provincial government industrial investment funds need to play

the role of "weather vane" and "patient capital", focusing on key areas such as underlying technologies and common platforms that the market is reluant to intervene in the early stage. At the same time, we will vigorously develop financial instruments such as science and technology insurance and intellectual property securitization to diversify innovation risks, and encourage social capital to share the long-term dividends of the digital economy through "investing early, investing in small, and investing in hard technology". Third, promote the construction of an open, shared, and application-focused technology empowerment network. The focus of technology policy should shift from funding the research and development of a single enterprise to supporting the construction of regional public computing power platforms, open source code warehouses and data open alliances, and lowering the threshold for small and medium-sized enterprises to obtain advanced technology. In particular, it is necessary to set up special projects to encourage platform enterprises and leading enterprises to open up technical interfaces and solutions to the upstream and downstream of the industrial chain, promote the in-depth application and integration and innovation of digital technology in traditional advantageous industries such as intelligent manufacturing and smart agriculture, and realize the multiplier effect of technology diffusion. Ultimately, all policies need to be systematically integrated and dynamically evaluated at the provincial level. It is recommended to establish a cross-departmental coordination mechanism for the development of the digital economy, regularly evaluate and adjust the combination and support intensity of talent, finance, and technology policies according to the factor endowment and development stage of each province, so as to ensure the formation of a positive cycle between factors, and finally realize the evolution of the digital economy from "one branch" in individual provinces to "a hundred flowers blooming" nationwide.

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