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*Original Paper*

# How Does Digital Industry Agglomeration Drive High-Quality Urban Development? An Analysis from Both Geographic and Virtual Perspectives

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***Abstract***

*In the digital economy era, the spatial organization of digital industry is evolving from geographic agglomeration to virtual-real integration, becoming a key driver of high-quality urban development. Using panel data from 30 provincial capital cities in China from 2013 to 2023, this paper examines the impact of digital industrial agglomeration on high-quality urban development from the dual perspectives of geographic agglomeration and virtual agglomeration. The results show that: (1) Both digital industry geographic agglomeration and virtual agglomeration significantly promote high-quality urban development, and geographic agglomeration presents an inverted-U relationship, first promoting and then inhibiting. (2) The impact of the two types of agglomeration has significant regional heterogeneity and agglomeration-level heterogeneity. Both types of agglomeration have their strongest promoting effect in the eastern region. Cities with low agglomeration levels mainly rely on scale expansion and digital capacity to accumulate and release potential. In contrast, cities with high agglomeration levels rely more on deepening innovation and optimizing spatial structure. (3) Both types of agglomeration have significant positive spatial spillover effects, which can promote the high-quality development of surrounding cities; however, when geographic agglomeration crosses the threshold, its spillover will be weakened. The conclusions of this paper provide policy implications for optimizing the spatial layout of the digital industry and promoting regional coordinated development.*

***Keywords***

*Digital industry, Geographic agglomeration, Virtual agglomeration, High-quality urban development*

## 1. Introduction

China's economy has shifted from a stage of high-speed growth to a stage of high-quality development. In the future modernization drive, the transformation of the development mode, the optimization of the economic structure, and the transformation of the growth momentum will be established as the key directions (Jing & Sun, 2019). Under the guidance of this major strategy, as the core carrier of high-quality development, the deep integration of urban transformation and upgrading with the digital industry has become an inevitable trend. Subsequently, the Third Plenary Session of the Party of China proposed to 'improve the mechanism for promoting the deep integration of the real economy and the digital economy,' with the deep integration of the digital economy and the construction of the modern industrial system as the goal orientation, highlighting the important role of the digital industry in the modernization of the urban industrial system and the development of new international competitive advantages. During the '15th Five-Year Plan' period, China's economic and social development will continue to promote high-quality development as the theme, adhere to the direction of intelligence, greening, and integration, accelerate national construction, and build a modern industrial system. As an important part of the modern industrial system, the digital industry has broken the geographical space restrictions of traditional industries by virtue of the virtuality and strong permeability of digital technology (Zhao et al., 2024), promoting the evolution of industrial form from physical agglomeration to virtual and real integration, and giving birth to a new ecology of digital industrialization dominated by Internet platforms and the coordinated development of industrial digitalization supported by big data (Zhao et al., 2024). The development of the digital industry is an important strategic fulcrum to improve the comprehensive competitiveness of cities and promote the upgrading of city functions and competitiveness. It is also the key path for cities to achieve high-quality development and build a modern economic system.

The traditional industrial agglomeration theory emphasizes that the same industry and its related industries form clusters through specialized division of labor in a specific geographical space (Hu et al., 2018). This can produce scale effects that reduce costs and promote knowledge spillover and enterprise competition through geographical proximity, thereby improving the level of technological innovation and resource allocation efficiency (Li et al., 2018). However, this model may also lead to the convergence of behavior among enterprises and the simplification of industrial structure, thus strengthening path dependence, forming a closed system, and inhibiting the absorption capacity of new knowledge in the region, which is not conducive to the long-term development of the city (Li et al., 2020). The rise of the digital economy is promoting a systematic change in the form of industrial agglomeration. With its virtuality and strong permeability, digital technology has spawned new formats, new models, and new kinetic energy through the integration and application of traditional industries, which has promoted industrial agglomeration from traditional geospatial agglomeration to more flexible virtual agglomeration. Virtual agglomeration takes the real-time exchange of data and information as the core link, which greatly improves the means and efficiency of information and knowledge exchange in the Internet of Things, artificial intelligence, and other technologies, and reduces dependence on

geographical proximity (Wang et al., 2018). While giving full play to the advantages of traditional agglomeration functions, it can also effectively avoid negative problems such as the crowding effect (Jin & Meng, 2024) and inject new vitality into regional innovation.

As a hot topic in today's society, industrial agglomeration has attracted scholars' attention, and most studies examine its impact on urban development from two dimensions. One is geographical agglomeration, which focuses on optimizing resource allocation through geographical proximity, accelerating knowledge spillover and technology diffusion, and thereby driving improvements in regional innovation efficiency and the upgrading of the industrial structure (Zhao et al., 2025; Gao & Yuan, 2020). The second is virtual agglomeration, which explores its growth effects, such as promoting green economic development by fostering new business forms and expanding industrial chains (Chai et al., 2024). In recent years, some scholars have begun to combine the two to explore their integration mechanism. For example, one study analyzes the geographical agglomeration pattern of the digital economy at the provincial level and its impact on regional economic development through mechanisms such as knowledge spillover and technology diffusion (Pan et al., 2021); another demonstrates how to improve the level of virtual agglomeration of enterprises to promote the improvement of total factor productivity and enable the high-quality development of the urban economy as the key driving force of public data opening (Guo et al., 2025). From the perspective of integration, it is proposed that digital technology can break geographical restrictions, promote regional coordinated division of labor and optimal allocation of resources, and thereby improve the high-quality development level of the urban economy (Wang & Yang, 2024). Few studies have incorporated geographical and virtual agglomeration into the same analytical framework to explore their differentiated impacts on urban high-quality development and spatial interaction mechanisms.

In view of this, this paper aims to systematically analyze the effects of the two on the high-quality development of the city from the perspective of the integration of the 'geographical-virtual' dual agglomeration of the digital industry, and to use the spatial econometric model to study the spatial spillover effect of industrial agglomeration on the high-quality development of the city. It conducts an in-depth study of the spatial dependence between the two to address the theoretical gap in existing research, which focuses on a single dimension.

## 2. Theoretical Analysis and Research Hypothesis

### *2.1 Geographical Agglomeration of Digital Industry and High-quality Urban Development*

The agglomeration of industries in geographic space will bring about external economies of scale. In this process, it often leads to significant cost reductions, optimizes production processes (Han et al., 2025), and concentrates production factors. For the digital industry, relying on its technical characteristics and network effects, it can further strengthen the external economies brought by geographic agglomeration and become an important engine driving high-quality urban development. However, with the continuous improvement of the degree of agglomeration, problems such as resource overcrowding, intensified

competition, and a decline in factor allocation efficiency may appear, resulting in the non-linear evolution characteristics of the agglomeration effect that first promotes and then inhibits.

First, digital industry agglomeration has the advantage of resource sharing. By sharing digital infrastructure, it avoids the waste of resources caused by repeated construction. At the same time, it is easier for upstream and downstream enterprises in the geographically adjacent supply chain to establish a cooperative relationship of mutual trust, which is conducive to reducing transaction costs (Serpa & Krishnan, 2018), thus freeing up more resources for technology research and development and model innovation, promoting the construction of an open and coordinated industrial ecology, and injecting vitality into the high-quality development of the city. However, when the agglomeration scale exceeds a reasonable threshold, the infrastructure carrying pressure intensifies, and competition for shared resources becomes fierce, which may lead to a decline in resource utilization efficiency and weaken the positive effect of resource sharing. Second, the geographical agglomeration of the digital industry promotes the coordinated development of enterprise production. With the continuous development of the market and the continuous differentiation and integration within the industry, the geographical agglomeration of the digital industry realizes the concentration of high-tech labor, capital, massive data, talents, and other production factors. It promotes relevant enterprises and institutions to realize the cross-chain cooperation and network cooperation of the industrial chain through collaborative agglomeration (Wang & Wang, 2023; Xin, 2023). On the one hand, the technology spillover brought by data sharing, infrastructure sharing, and geographical proximity among enterprises promotes the standardization and synergy of production processes; on the other hand, geographical agglomeration reduces the communication and logistics costs of upstream and downstream enterprises, so that the industrial chain in the region can respond more flexibly to market changes and improve the operational efficiency and anti-risk ability of the overall industrial chain. However, excessive agglomeration can easily lead to problems such as intensified industrial homogenization competition and mismatch of production factors, which will not only offset the positive effect of collaborative cooperation, but also increase the internal friction of the industrial chain and restrict the quality of coordinated development of production. Third, the geographical agglomeration of the digital industry promotes the accumulation and concentration of factor resources. As an advanced form of industrial agglomeration, digital industry agglomeration can accelerate the agglomeration of innovation factors such as human capital, technology, and capital, provide key support for technological innovation (Zhao et al., 2024), and help the industry achieve transformation and upgrading. At the same time, using data analysis technology to mine the value of data resources will help enterprises obtain effective references for decision-making and industrial layout, and provide a foundation and innovation momentum for high-quality urban development. Similarly, when the degree of agglomeration is too high, the excessive concentration of factors can easily lead to problems such as local resource redundancy and insufficient innovation incentives. On the contrary, it will inhibit the efficiency of factor capital allocation and weaken the positive driving effect on high-quality urban development. Based on the above analysis, this paper proposes the following hypotheses:

H1: The effect of geographical agglomeration on high-quality urban development is inverted-U-shaped, first increasing and then decreasing.

*2.2 Virtual Agglomeration of Digital Industry and High-quality Urban Development*

Against the backdrop of the deep integration of digital technology and the real economy, the agglomeration form of industry is gradually taking on a new feature of "combination of virtual and real." Virtual agglomeration is not meant to replace the traditional agglomeration model based on geographical proximity, but to build a more flexible and efficient modern economic system through collaborative interaction with geographical agglomeration, and to jointly drive high-quality urban development.

First, virtual agglomeration uses the network platform built by digital technology to break the shackles of geographical space on the flow of factors, so that production factors can flow freely and match efficiently, improve the spatial allocation and utilization of resources (Wang et al., 2018), and provide basic support for high-quality urban development. Second, virtual agglomeration promotes the modular decomposition and dynamic reorganization of each link in the industrial chain, and promotes the rapid flow and reallocation of production factors according to market changes (Wang & Zhang, 2025), so as to achieve real-time convergence and coordination across regions. In this way, the industry can break through the limitations of physical space and reconstruct its traditional behavior pattern. At the same time, traditional elements can be concentrated in areas with comparative advantages, and cross-regional deployment and use can be realized through a virtual agglomeration network (Zhao & Zhang, 2025), thus realizing the flexible layout and dynamic optimization of the industrial chain and improving the overall collaboration efficiency and industrial resilience. Finally, virtual agglomeration effectively alleviates the spatial blocking problem of knowledge spillover, improves the frequency of information exchange and knowledge learning ability among innovation subjects, and promotes knowledge sharing and technical cooperation (Wang & Zhou, 2021). Enterprises that are related in knowledge can not only obtain digital dividends from information sharing and real-time interaction, but also help break through the path dependence of innovation and development of urban traditional industries (Liu et al., 2023). By strengthening the interaction between economic entities across time and space, virtual agglomeration has become an important driving force for the improvement of urban innovation ability and has promoted high-quality urban development. Based on the above analysis, this paper proposes the following hypotheses:

H2: The virtual agglomeration effect of the digital industry improves the level of high-quality urban development. The higher the level of virtual agglomeration, the more conducive it is to high-quality urban development.

*2.3 Spatial Spillover Effects of Digital Industry Agglomeration*

Digital industrial agglomeration can not only directly drive the city's high-quality development through resource optimization, industrial synergy, and knowledge spillover effects (Xin, 2023), but also affect neighboring areas through spatial spillover effects. However, the direction and intensity of the regional effect are influenced by the level of industrial synergy between cities and the development stage of

geographical agglomeration in the region.

Within the framework of effective inter-city cooperation, geographical and virtual agglomeration can reinforce each other and jointly advance regional integration. On the one hand, core cities rely on the economies of scale and the industrial ecology formed by geographical agglomeration, leveraging geographical proximity to strengthen regional cooperation and competition and optimize inter-regional resource allocation through spillover and diffusion effects (Zhao & Wei, 2019; Heo & Lee, 2019). However, moderate local geographical agglomeration is an important prerequisite for positive spillover. On the other hand, virtual agglomeration breaks through spatial constraints with the help of digital technology, promotes the cross-regional real-time flow and allocation of data, information, and knowledge, and improves regional resource utilization and collaborative innovation capabilities (Xie et al., 2024). It has become a key channel for the agglomeration effect to spread outward. This not only builds an innovative collaboration network across cities but also enables surrounding cities to absorb the radiation from core cities, accelerates local industrial upgrading and innovative development, and ultimately promotes the overall development of urban agglomerations toward high-quality development. However, if there is a lack of an effective coordination mechanism between cities, or excessive geographical agglomeration of local industries, digital industry agglomeration may also aggravate the imbalance of regional development. Relying on economies of scale, geographical agglomeration may continue to attract capital and high-end factors from surrounding areas to the region, and the crowding cost caused by excessive agglomeration may weaken its external diffusion momentum. In the absence of collaborative governance, the efficient information network formed by virtual agglomeration may accelerate the one-way flow of such elements and strengthen the 'siphon effect' of the center. At the same time, differences in digital infrastructure (Yin et al., 2025), policy environment, and innovation ecology between regions will form invisible barriers, hinder the cross-regional transmission of spillover effects such as knowledge and technology, and may further converge to the core region due to high-end factors such as data and computing power, aggravate the 'digital divide' between regions, and make the surrounding cities face problems such as factor loss and industrial upgrading, thus inhibiting their high-quality economic development. Therefore, this paper puts forward the hypothesis:

H3a: There is a spatial spillover effect on the impact of the digital industry's geographical agglomeration on urban high-quality development.

H3b: There is a spatial spillover effect on the impact of the digital industry's virtual agglomeration on urban high-quality development.

## 3. Models and Data

### *3.1 Research Model*

#### 3.1.1 Benchmark Regression Model

Based on the theoretical analysis above, a two-way fixed effects model is used to test the impact of digital industry geographical agglomeration and virtual agglomeration on urban high-quality development.

Given the potential non-linear relationship between digital industry geographical agglomeration and urban high-quality development, this paper introduces the quadratic term $Agg^2$ of the core explanatory variable into the benchmark model and establishes the following model:

$$Qua_{it} = \alpha_0 + \alpha_1 Agg_{it} + \alpha_2 Vagg_{it} + \alpha_3 Agg_{it}^{\ 2} + \alpha_4 X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

Subscript i denotes the city, and subscript t denotes the year. The dependent variable is Qua, representing the level of high-quality urban development; The core explanatory variables are Vagg, representing the level of virtual agglomeration; and Agg, representing the level of geographical agglomeration. X are the control variables. $\mu$ is the urban fixed effect, $\delta$ is the time fixed effect, and $\varepsilon$ epsilon is the random disturbance term.

3.1.2 Spatial Econometric Model

To further test the spillover effects of geographic and virtual agglomeration in the digital industry on urban high-quality development, this paper uses the spatial lag model to investigate spatial spillovers. The basic model is as follows:

$$Qua_{it} = \lambda_0 + \lambda_1 Agg_{it} + \lambda_2 Vagg_{it} + \lambda_3 Agg_{it}^{\ 2} + \rho WQua_{it} + \lambda_4 X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

Among them, $\rho$ represents the spatial autoregressive coefficient, and W represents the spatial weight matrix. This paper uses the economic-distance weight matrix.

*3.2 Variable Selection*

3.2.1 Explained Variable: High-quality Urban Development

High-quality development is the key path to promoting Chinese-style modernization. In the transition from high-speed to high-quality growth, the economy faces challenges such as industrial transformation and upgrading and development imbalances. It is necessary to coordinate regional balanced development and green development through innovation, optimize the development structure while protecting the ecological environment, and achieve multifaceted improvement. Following the practice of Wei et al. (2020) and Liu et al. (2021), a comprehensive index evaluation system is used to measure the level of high-quality urban development. From the five dimensions of 'innovation, coordination, green, openness, and sharing,' 14 indicators are selected to measure the level of high-quality economic development. The entropy method is used to obtain the comprehensive index of high-quality development (Qua). The larger the value, the higher the level of high-quality urban development. The index system is shown in Table 1.

**Table 1. Comprehensive Index System of Urban High-quality Development**

| First-grade indexes | Second index | Index explanation | Property |
|---|---|---|---|
| High-Quality Development | Innovation | Scientific Investment (10,000 yuan) | + |
| | | Number of Patents Granted (items) | + |
| | Coordination | Financial Development (%) | + |
| | | Disparity Between Urban and Rural Residents (%) | - |
| | | Industrial Coordination (%) | + |
| | Green | PM2.5 (micrograms per cubic meter) | - |
| | | Per Capita Green Space and Park Area (square meters) | + |
| | | Harmless Waste Treatment Rate (%) | + |
| | Openness | Total Import and Export Value (USD 100 million) | + |
| | | Actual Utilization of Foreign Investment for the Year (USD 100 million) | + |
| | Shared | Wages of Employees on the Job (yuan) | + |
| | | Per capita urban road area (square meters) | + |
| | | Number of hospital beds (units) | + |
| | | Consumption Level (%) | + |

3.2.2 Core Explanatory Variables

The agglomeration of the digital industry is a phenomenon characterized by the concentration of digital infrastructure and digital technology within a specific geographic area. It essentially improves resource allocation and coordination through sharing. Common measures of industrial agglomeration include the Herfindahl index, industrial concentration, and the location quotient. Among these, the location quotient is not affected by regional scale and better reflects the spatial distribution of the factors (Su et al., 2018). Therefore, this paper draws on the practice of Xu & Yu (2024) and uses the location quotient of the number of digital industry employees in the region to measure the degree of geographical agglomeration. The specific calculation formula is as follows:

$$\mathrm{Agg}_{it} = (q_{it} / h_{it}) / (q_t / h_t)$$

In the formula, $q_{it}$ and $h_{it}$ represent the number of employees in the information transmission, software, and information service industries and the total number of employees in city i in year t, respectively. $q_t$ and $h_t$ represent the number of employees in the information transmission, software, and information service industries and the total number of employees in year t, respectively.

Virtual agglomeration is a new organizational form that combines traditional industrial geospatial agglomeration with Internet Plus. It can reflect the agglomeration level of virtual space in the digital industry using digital technology. It is a new form of industrial agglomeration, but no consensus has been

reached on its measurement. This paper refers to the research of Zhang et al. (2024) constructs a comprehensive evaluation index system from the virtual network interaction of the urban digital industry and the external resource support dimension of the urban digital industry, and uses the entropy method to calculate the comprehensive score. The specific indicators are shown in Table 2.

**Table 2. Digital Industry Virtual Agglomeration Comprehensive Index System**

| Measure dimension | Specific indicators | Measurement | Source |
|---|---|---|---|
| Virtual network interaction of urban digital industry | Virtual network interaction between cities | Baidu index | Zhang et al. (2024) |
| | Online trading index | E-commerce transactions | Ji & Niu (2023) |
| | Virtual network interaction function | Number of patent applications per 10,000 people in the digital industry | Song et al. (2024) |
| External resource support of urban digital industry | The development level of digital finance | Peking University Digital Inclusive Finance Index | Guo et al. (2020) |
| | Urban industrial base | Share of the tertiary industry in GDP | Wang et al. (2024) |

3.2.3 Control Variable

Refer to the practices of Zhao & Xu (2023) and Deng & Zhang (2022) This paper selects the following variables as the urban development indicators that may have an impact on the high-quality development of the city as control variables, specifically: (1) population size (pop), which is represented by urban population density; (2) the level of financial activity (fin), measured by the total amount of deposits and loans of regional institutions; (3) government intervention (GOV), which is expressed by the ratio of fiscal budget revenue to local GDP; (4) the level of economic development (gdp), expressed as per capita GDP, and processed by logarithm; (5) The level of human capital (highedu), the number of college students per 10,000 people; (6) The degree of fiscal decentralization (finadp) is expressed by the ratio of government revenue to government expenditure.

*3.3 Sample Selection and Data Description*

This paper selects the panel data for 30 provincial capitals in China from 2013 to 2023. Due to the large number of missing values in Lhasa, the city is excluded. The research data are mainly obtained from the ' China City Statistical Yearbook ', the statistical yearbooks and statistical bulletins of cities, EPS, and the Incopat patent database. Among them, the virtual network interaction index between cities is obtained by constructing a weighted asymmetric matrix from the Baidu search index between pairs of cities. The larger the search index value between two cities, the greater the virtual information flow between the two

cities. After obtaining the weighted asymmetric matrix, the degree centrality from social network analysis is used to measure the interaction relationship and influence of the urban virtual network Zhang et al. (2024). The Digital Inclusive Finance Index is derived from the database of Peking University Digital Finance Research Center. Some missing data in the remaining few cities are supplemented by interpolation and the moving average method.

## 4. Empirical Results and Analysis

### *4.1 Benchmark Regression Results*

The regression results of the impact of digital industry geographical agglomeration and virtual agglomeration on urban high-quality development are shown in Table 3. In columns (1) and (2), under the fixed effects of time and city, the influence coefficients of geographic agglomeration variables and virtual agglomeration variables of China's digital industry on high-quality urban development are positive, and both are significant at the 1% level. After adding control variables, the results of columns (3) and (4) are still significantly positive at the 1% level, indicating that the geographical agglomeration and virtual agglomeration of the digital industry significantly improve the level of high-quality urban development. Column (5) puts geographical agglomeration and virtual agglomeration into the empirical model at the same time to verify the relationship between the two and high-quality development. Column (6) of Table 3 shows that the linear and quadratic terms of the geographical agglomeration of the independent variables have a non-linear impact on the city's high-quality development at the 1% significance level, and the impact direction is positive first and then negative. The significance of the remaining variables remains unchanged. The results indicate an inverted 'U' relationship between the geographical agglomeration of the digital industry and high-quality urban development, with a turning point of 0.474 as identified by the Lind–Mehlum U-test. In the sample, this turning point is of practical significance, and the hypothesis H1 is verified. At present, in the process of digital industry development, virtual agglomeration relies on digital technology to break through the limitations of geographical space, which can effectively avoid negative problems such as the crowding effect caused by excessive development of traditional geographical agglomeration. At the same time, virtual agglomeration enables the positive effects of knowledge spillover and economies of scale brought by geographical agglomeration to be released in a wider range. By efficiently integrating resources across regions and reducing transaction and collaboration costs, it not only offsets the diminishing marginal returns that geographical agglomeration may face, but also provides continuous impetus for industrial upgrading and innovation.

**Table 3. Benchmark Regression Results**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Qua | Qua | Qua | Qua | Qua | Qua |
| Agg | 0.0456*** | | 0.0571*** | | 0.0344*** | 0.0549*** |
| | (3.56) | | (4.50) | | (2.59) | (4.06) |
| Vagg | | 0.2509*** | | 0.3002*** | 0.2559*** | 0.2255*** |
| | | (6.37) | | (6.46) | (5.40) | (4.83) |
| $Agg^2$ | | | | | | -0.0579*** |
| | | | | | | (-4.96) |
| highedu | | | 0.0805** | 0.1108*** | 0.1038*** | 0.1315*** |
| | | | (2.21) | (3.05) | (3.01) | (3.79) |
| finadp | | | 0.0001 | -0.0520 | -0.0344 | -0.0108 |
| | | | (0.00) | (-1.43) | (-1.04) | (-0.34) |
| fin | | | -0.0201*** | -0.0200*** | -0.0207*** | -0.0217*** |
| | | | (-3.26) | (-3.32) | (-3.48) | (-3.73) |
| pop | | | 0.0138 | 0.1333 | 0.0114 | 0.2554 |
| | | | (0.08) | (1.00) | (0.08) | (1.62) |
| gov | | | 0.5444*** | 0.4574*** | 0.5056*** | 0.5531*** |
| | | | (3.11) | (2.74) | (3.02) | (3.39) |
| gdp | | | 0.0045 | 0.0071 | 0.0151 | -0.0002 |
| | | | (0.14) | (0.22) | (0.51) | (-0.01) |
| ID Fixed | YES | YES | YES | YES | YES | YES |
| YEAR Fixed | YES | YES | YES | YES | YES | YES |
| Observations | 330 | 330 | 330 | 330 | 330 | 330 |
| Adj R2 | 0.9748 | 0.9760 | 0.9775 | 0.9792 | 0.9797 | 0.9808 |

*4.2 Robustness Checks*

To ensure the robustness of the benchmark regression results, this section uses three approaches: replacing the explained variable, eliminating the special years affected by the COVID-19 epidemic, and excluding municipalities directly under the central government. The specific results are shown in Table 4. First, to replace the explanatory variables, following Liu & Zhang (2021), principal component analysis is used to measure the city's high-quality development level. In the study of the impact of digital industry agglomeration on urban high-quality development, principal component analysis was used to extract common factors with eigenvalues greater than 1, yielding three common factors with a cumulative variance contribution rate of 69.28%. The regression results are shown in column (1) of the table. The coefficients of geographical agglomeration and virtual agglomeration are positive and significant at the

1% level, and the quadratic term of geographical agglomeration is negative and significant at the 1% level. Secondly, because municipalities directly under the central government tend to receive more resources and government support in the development process, Beijing, Tianjin, Shanghai, and Chongqing—the four municipalities directly under the central government—are excluded. As shown in column (2) of the table, the coefficients of geographical agglomeration and virtual agglomeration are positive and significant at the 1% level, and the quadratic term of geographical agglomeration is negative and significant at the 1% level. Thirdly, considering the impact of the COVID-19 epidemic on urban development and economic level, the sample data between 2020 and 2022 are excluded, and the regression is carried out again. The results are shown in column (3) of the table. The regression coefficients of the core explanatory variables remain positive and significant, and the quadratic term of geographical agglomeration is negative and significant at the 1% level. These results indicate that, after eliminating special years, geographical agglomeration and virtual agglomeration can still improve the level of high-quality urban development in the context of the digital industry, and there is an inverted U-shaped relationship between geographical agglomeration and high-quality urban development.

**Table 4. Robustness Checks Test**

| | (1) Replace the explained variable | (2) Excluding municipalities directly under the central government | (3) Exclude the epidemic year |
|---|---|---|---|
| Agg | 1.1658*** | 0.0562*** | 0.0504*** |
| | (6.65) | (5.06) | (2.99) |
| Vagg | 1.9632*** | 0.1885*** | 0.2418*** |
| | (3.82) | (5.59) | (4.02) |
| $Agg^2$ | -0.8867*** | -0.0546*** | -0.0397** |
| | (-4.59) | (-5.35) | (-2.29) |
| Control | YES | YES | YES |
| ID Fixed | YES | YES | YES |
| YEAR Fixed | YES | YES | YES |
| Observations | 330 | 286 | 240 |
| Adj R2 | 0.9579 | 0.9795 | 0.9575 |

*4.3 Endogeneity Treatment*

When conducting baseline regression, the references may cause endogeneity problems due to missing variables, measurement errors, reverse causality, etc. In order to solve this problem, this paper uses the instrumental variable method to test the endogenous problems that may exist in the model. Specifically, the geographical agglomeration and virtual agglomeration of the core explanatory variables are lagged

by one period as instrumental variables, and the two-stage least squares method (2SLS) is used to estimate. The results are shown in Table 5. Columns (1) and (3) report the results of the first stage of geographical agglomeration and virtual agglomeration lag as instrumental variables, respectively, showing that the instrumental variables are significantly correlated with the endogenous variables. The P values of the two core explanatory variables in the table are less than 0.01, and the F values are far greater than the threshold at the 10% significance level, indicating that the instrumental variables are identifiable and there is no weak instrumental variable problem, indicating that the selection of instrumental variables in this paper is reasonable. Columns (2) and (4) report the results of the second stage of geographical agglomeration and virtual agglomeration as instrumental variables, respectively. It shows that after dealing with endogenous problems, the impact of geographical agglomeration and virtual agglomeration on urban high-quality development under the digital industry is still significantly positive at the 1% level, and the quadratic term of geographical agglomeration is significantly negative at the 1% level. After introducing instrumental variables, the regression results are still robust, and it is further verified that digital industry geographic agglomeration and virtual agglomeration can effectively improve the level of high-quality urban development, and geographical agglomeration has an inverted-U effect on high-quality urban development.

**Table 5. Endogenous Treatment**

| | Geographical agglomeration | | Virtual agglomeration | |
|---|---|---|---|---|
| | First stage | Second stage | First stage | Second stage |
| | (1) | (2) | (3) | (4) |
| Agg | | 0.0546*** | | 0.0258* |
| | | (2.78) | | (1.71) |
| Vagg | | 0.1592*** | | 0.2947*** |
| | | (3.12) | | (3.59) |
| L.Agg | 0.6584*** | | | |
| | (11.48) | | | |
| L.Vagg | | | 0.5308*** | |
| | | | (6.46) | |
| Control | YES | YES | YES | YES |
| ID Fixed | YES | YES | YES | YES |
| YEAR Fixed | YES | YES | YES | YES |
| Observations | 300 | 300 | 300 | 300 |
| LM statistic | | 35.90*** | | 38.79*** |
| Wald F statistic | | 131.887 | | 41.668 |

*4.4 Heterogeneity Analysis*

4.4.1 Regional Heterogeneity

Given the significant differences in resource endowments, economic foundations, and digital infrastructure across China's regions, uneven development may lead to heterogeneous effects of digital industry agglomeration on urban high-quality development. Therefore, based on the National Bureau of Statistics' regional division standard, this paper divides the 30 provincial capital cities in China into eastern, central, and western regions according to the current state of regional economic development. Using grouped regressions, this paper empirically tests the differential impact of digital industry geographic agglomeration and virtual agglomeration on high-quality urban development in different regions from a regional perspective. The results are shown in Table 6.

Digital industry geographic agglomeration has a significant effect on cities' high-quality development in the eastern and central regions, but not in the western region. The quadratic term is only significant in the east, indicating that the agglomeration in the eastern region has approached saturation, showing an inverted U-shaped feature of ' promoting first and then inhibiting '. This is because the eastern region benefits from the geographical advantages of early policy dividends and traditional agglomeration, and the concentration of enterprises and resources helps form economies of scale. However, as agglomeration exceeds a reasonable threshold, crowding effects such as rising labor costs and traffic congestion appear, weakening the positive effect of its economies of scale and the marginal promotion effect. The central region is in the stage of rapid development of industrialization and digitization. The industrial foundation is solid, the agglomeration level is not saturated, and there is still much room for improvement. Against the background of the continuous release of the synergistic effect of digital technology and traditional industry, its promotional effect is significant and, as the agglomeration level is not yet saturated, has greater potential for further release. The western region is limited by a weak industrial foundation, brain drain, and unbalanced internal development. It has not yet broken through the " development threshold " required for knowledge spillover, technology diffusion, and economies of scale, and the driving effect is not significant.

The impact of virtual agglomeration on high-quality urban development in the eastern, central, and western regions is significantly positive, and the coefficients display a gradient: the eastern region is the best, followed by the western and central regions. This pattern reflects structural differences in digital infrastructure, technological ecology, and industrial base across regions. The eastern region has robust digital infrastructure and a mature network ecology, which provide solid support for virtual agglomeration. Virtual agglomeration can not only transcend geographic boundaries and alleviate the crowding effects of excessive agglomeration, but also strengthen knowledge spillovers and technology diffusion through digital technology, thereby enabling optimal resource allocation and innovation linkage, producing a significant driving effect. The infrastructure and information technology of the digital industry in the central region are developing rapidly, but there remains a gap compared with the eastern coast. Because the operational efficiency of virtual agglomeration is highly dependent on underlying

digital technology, its potential has not yet been fully realized, and its driving role is weaker than that of the east. The foundation of the digital industry in western China is relatively weak, but virtual agglomeration relies on 'Internet+' technology empowerment, which can effectively overcome geospatial constraints, help enterprises obtain information and factor resources at a lower cost, promote cross-regional coordination and resource optimization, so as to bypass the 'development threshold' of traditional geographical agglomeration, and have a significant and independent positive impact on local high-quality development.

Based on the above analysis, combined with the quantitative results in Table 6 and recent developments, the two types of agglomeration in the west have significant potential that has not yet been fully realized and should become the strategic focus of national urban construction and industrial layout. It is suggested that the region prioritize the development of virtual agglomeration to overcome geographic constraints, integrate intra- and cross-regional factor resources with the help of the Internet Plus, improve digital infrastructure and the industrial base, and steadily promote high-quality development through regional coordination. The central region should jointly promote both types of agglomeration, optimize the coordination mechanism for traditional industries with digital technology, and improve the efficiency of industrial chain operations. As the first-mover region of the digital industry, the eastern region should focus on ' structural optimization ' and ' efficiency improvement ', strengthen virtual agglomeration to alleviate the crowding effect caused by excessive geographic concentration, fully leverage the integration and coordination ability of cross-regional resources, promote the upgrading of industries to high-end links, and enhance the digital penetration and innovation ability of traditional industries.

**Table 6. Regional Heterogeneity Test**

| | Eastern | Central | Western |
|---|---|---|---|
| | (1) | (2) | (3) |
| Agg | 0.1243*** | 0.0649*** | 0.0074 |
| | (3.41) | (3.01) | (0.25) |
| Vagg | 0.3123** | 0.1273* | 0.1327*** |
| | (2.12) | (1.86) | (3.34) |
| $Agg^2$ | -0.0919*** | -0.0666 | -0.0355 |
| | (-3.68) | (-0.85) | (-0.80) |
| Control | YES | YES | YES |
| ID Fixed | YES | YES | YES |
| YEAR Fixed | YES | YES | YES |
| Observations | 121 | 88 | 121 |
| Adj $R^2$ | 0.9838 | 0.9325 | 0.9628 |
| Chow Test | 1.94[0.075] | | |

#### 4.4.2 Heterogeneity of Agglomeration Level

The impact of geographical agglomeration and virtual agglomeration of the digital industry on high-quality urban development may be different due to the different levels of agglomeration development in different regions. In order to further study the development path of cities at different levels of agglomeration, this paper divides the overall sample into higher and lower groups of geographical agglomeration level and virtual agglomeration level according to the median of geographical agglomeration and virtual agglomeration level, and conduct group regression. The results are shown in Table 7. In column (1), when geographical agglomeration is at a low level, both core explanatory variables are positive and significant. This shows that such cities can still promote development by increasing the spatial density of real industries. At the same time, the quadratic coefficient is significantly positive; that is to say, these cities are far from reaching the inflection point of agglomeration economy and are still in the stage of increasing returns to scale. In column (2), when the geographical agglomeration is at a high level, only the virtual agglomeration coefficient is significantly positive, which indicates that the core tasks of a few more mature cities have shifted from scale expansion to quality improvement, and they need to rely more on innovation and digitization to achieve sustainable development. In column (3), when virtual agglomeration is low, only the virtual agglomeration coefficient is positive and significant. This indicates that for cities with a relatively weak digital foundation, developing a digital economy and strengthening digital connectivity are effective ways to promote high-quality development. This will help the region break through geographical constraints at a lower cost, access wider markets, and play its role of "catch-up" and "making up for shortcomings". In column (4), when virtual agglomeration is high, the first term of geographical agglomeration is positive and significant, while the second term is negative and significant. This indicates that for cities with leading digital development, after the relative improvement of digital infrastructure and the technology system, it is difficult to continue promoting development by relying solely on scale expansion. It is necessary to promote the transformation from "digital access" to "deep integration of digital and real" and "spatial structure optimization." By optimizing industrial layout and spatial planning, we can prevent and alleviate the negative impact of excessive agglomeration.

In summary, cities with different agglomeration levels are at different stages of development. Their high-quality development path should also be adapted to local conditions; that is, cities with lower agglomeration levels can release growth potential through scale expansion and digital access, while cities with higher agglomeration levels need to rely on innovation deepening and spatial optimization to achieve sustainable development.

**Table 7. Heterogeneity of Agglomeration Level Test**

| | Geographical agglomeration | | Virtual agglomeration | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | Low | High | Low | High |
| Agg | 0.2917*** | 0.0155 | 0.0203 | 0.1242*** |
| | (4.52) | (0.39) | (1.31) | (4.29) |
| Vagg | 0.2181*** | 0.2357* | 0.1999*** | 0.2011 |
| | (2.94) | (1.71) | (4.03) | (1.27) |
| Agg2 | 0.4830*** | -0.0358 | -0.0200 | -0.1023*** |
| | (3.64) | (-1.17) | (-0.82) | (-4.66) |
| Control | YES | YES | YES | YES |
| ID Fixed | YES | YES | YES | YES |
| YEAR Fixed | YES | YES | YES | YES |
| Observations | 210 | 120 | 202 | 128 |
| Adj R2 | 0.9129 | 0.9884 | 0.9077 | 0.9860 |
| Chow Test | 4.62[0.001] | | 3.01[0.019] | |

## 5. Further Analysis

### *5.1 Global Spatial Correlation Analysis*

To further verify Hypothesis 3, a spatial correlation test is conducted first. This paper uses Moran's I index to test the spatial autocorrelation of urban high-quality development, geographical agglomeration, and virtual agglomeration, and to assess whether there is spatial autocorrelation among them. It also calculates the Moran's I index for the standardized weight matrix and its statistical test results. Table 8 reports the global Moran index for the relevant variables of 30 provincial capital cities from 2013 to 2023. It can be seen that the variables are significantly positive at the 10% level or better. This indicates that high-quality urban development, geographical agglomeration, and virtual agglomeration have significant positive correlation effects, and that there is a certain agglomeration effect in the spatial distribution; that is, cities with similar levels of high-quality development and digital industry agglomeration tend to cluster spatially. In other words, there is a linkage effect between high-quality urban development and agglomeration. The development of the city is not an independent event but is affected by the development of neighboring cities.

**Table 8. Spatial Autocorrelation Test Results**

| | High-quality urban development | | Geographical agglomeration | | Virtual agglomeration | |
|---|---|---|---|---|---|---|
| Year | I | P-value | I | P-value | I | P-value |
| 2013 | 0.086 | 0.068 | 0.180 | 0.002 | 0.187 | 0.002 |
| 2014 | 0.075 | 0.070 | 0.166 | 0.004 | 0.158 | 0.006 |
| 2015 | 0.092 | 0.047 | 0.177 | 0.002 | 0.170 | 0.004 |
| 2016 | 0.102 | 0.033 | 0.172 | 0.003 | 0.168 | 0.005 |
| 2017 | 0.100 | 0.032 | 0.168 | 0.004 | 0.177 | 0.003 |
| 2018 | 0.096 | 0.036 | 0.178 | 0.003 | 0.183 | 0.002 |
| 2019 | 0.106 | 0.026 | 0.106 | 0.043 | 0.179 | 0.003 |
| 2020 | 0.126 | 0.010 | 0.127 | 0.018 | 0.179 | 0.003 |
| 2021 | 0.122 | 0.013 | 0.150 | 0.007 | 0.184 | 0.002 |
| 2022 | 0.133 | 0.008 | 0.121 | 0.025 | 0.189 | 0.002 |
| 2023 | 0.136 | 0.006 | 0.092 | 0.071 | 0.191 | 0.001 |

*5.2 Spatial Spillover Effect*

In order to select the appropriate spatial econometric model, based on the LM test, this paper adopts the spatial lag model (SAR). Through the Hausman test, goodness-of-fit, log-likelihood, and other tests, the individual fixed SAR model is selected to test the spatial effect of digital industry geographical agglomeration and virtual agglomeration on urban high-quality development.

Column (1) of Table 9 reports the regression results of the spatial lag model. The results show that the estimated coefficients of the core variables, digital industry agglomeration, are significantly positive, indicating that the improvement of the level of digital industry agglomeration can promote high-quality urban development in the region. At the same time, geographical agglomeration presents an 'inverted U-shaped' nonlinear influence characteristic that first promotes and then inhibits. The spatial autoregressive coefficient in the model is significantly positive, indicating that the digital industry agglomeration has a positive spatial spillover effect on the high-quality development of the city; that is, the geographical agglomeration and virtual agglomeration of the digital industry in the region are not only conducive to local development, but also have a positive spillover effect on the urban development of neighboring areas.

In order to further study the spatial effect of geographical agglomeration and virtual agglomeration of the digital industry on high-quality development, this paper uses the partial differential method to decompose the spatial effect of the individual fixed-effect model. The direct effect measures the influence of the change in explanatory variables on the dependent variables in the region; the indirect effect measures the influence of the change in explanatory variables on the dependent variables in the surrounding areas; and the total effect is the sum of the two. The results are shown in columns (2) to (4)

in Table 9. The direct and total effect coefficients of geographical agglomeration and virtual agglomeration are significantly positive, indicating that whether it is based on geographically adjacent physical agglomeration or virtual agglomeration based on digital connection, it can directly promote local innovation activities and optimize industrial distribution through mechanisms such as resource sharing, collaborative innovation and efficiency improvement, improve resource allocation efficiency and economic efficiency, and inject new momentum into high-quality urban development. In the indirect effect, the regression coefficients of geographical agglomeration and virtual agglomeration are also significantly positive. Both of them have positive spatial spillover effects on high-quality urban development, and H3a and H3b are verified. It is worth noting that the quadratic term of geographical agglomeration is significantly negative in the direct effect, indirect effect, and total effect. Combined with the result that its first term is significantly positive, it shows that the impact of geographical agglomeration on the high-quality development of local and surrounding areas presents an ' inverted U-shaped ' nonlinear relationship. That is, with the increase in the agglomeration level, its promotion effect on the high-quality development of local and surrounding cities first increases and then decreases, and there is an optimal agglomeration threshold; when the agglomeration level exceeds this threshold, the crowding effect will gradually become prominent, and the inhibitory effect will strengthen, thus weakening its positive driving effect on high-quality development.

**Table 9. Spatial Spillover Effects**

| | Ind | Direct | Indirect | Total |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Agg | 0.0589*** | 0.0617*** | 0.0175** | 0.0791*** |
| | (4.59) | (4.87) | (2.12) | (4.41) |
| Vagg | 0.1905*** | 0.1690*** | 0.0476** | 0.2166*** |
| | (4.38) | (4.13) | (2.10) | (3.93) |
| $Agg^2$ | -0.0491*** | -0.0564*** | -0.0161** | -0.0725*** |
| | (-3.50) | (-4.30) | (-2.04) | (-3.89) |
| rho | 0.2189*** | | | |
| | (3.06) | | | |
| sigma2_e | 0.0006*** | | | |
| | (12.82) | | | |
| Control | YES | YES | YES | YES |
| ID Fixed | YES | YES | YES | YES |
| YEAR Fixed | YES | YES | YES | YES |
| Observations | 330 | 330 | 330 | 330 |

## 6. Conclusion and Suggestions

### *6.1 Conclusion*

Based on data from 30 provincial capitals from 2013 to 2023, this paper empirically tests the impact of digital industry geographical agglomeration and virtual agglomeration on urban high-quality development by constructing an index system of urban high-quality development and virtual agglomeration, using panel econometric models and the spatial lag model. The study found that, first, the geographical agglomeration and virtual agglomeration of the digital industry can effectively promote the level of high-quality urban development. After robustness and endogeneity tests, the results are still valid. Second, the heterogeneity analysis shows that, at the regional level, the empowerment effect of geographical agglomeration is largest in the eastern region, while the central region, where agglomeration is not yet saturated, has greater potential for further release; the empowerment effect of virtual agglomeration is strongest in the eastern region. At low levels of both types of agglomeration, cities should pursue scale expansion and digital connectivity; at high levels, they should deepen innovation and optimize spatial structure. Third, the geographical agglomeration and virtual agglomeration of the digital industry have a significant positive spatial spillover effect on high-quality urban development. The geographical agglomeration and virtual agglomeration of the region will affect the high-quality development of neighboring areas through spillover effects. However, with the improvement of the level of geographical agglomeration, its promotion effect on the high-quality development of local and surrounding cities first increases and then decreases, and there is an optimal agglomeration threshold.

### *6.2 Policy Implications*

Based on the above research conclusions, this paper puts forward the following suggestions:

First, policymakers should implement a "two-wheel drive" agglomeration development path centered on virtual–real integration, and focus on strengthening the collaborative interaction between geographical and virtual agglomeration in the process of promoting digital industry agglomeration. On the one hand, they should continue to guide the digital industry to cluster geographically in advantageous regions, and fully leverage the advantages of infrastructure sharing, lower transaction costs, and face-to-face knowledge spillovers by building digital industrial parks and optimizing the factor supply structure. On the other hand, they should focus on cultivating and optimizing the virtual agglomeration ecosystem by strengthening new infrastructure such as 5G networks, computing power centers, and industrial Internet platforms, promoting the orderly circulation and open sharing of data elements, breaking down data barriers, and providing strong support for cross-regional networked cooperation, thereby releasing the synergistic empowerment effect of virtual–real integration to the greatest extent.

Second, implement a differentiated regional development strategy. The developed eastern region should focus on structural optimization and functional upgrading, further leverage the leading role of digital technology, strengthen basic research and development, promote the upgrading of the digital industry to high-end links, improve the virtual agglomeration ecology, deepen the integration of digital technology and the real economy, optimize the industrial competition environment, and enhance global

competitiveness. The central region should make full use of its industrial base and the advantages of agglomeration that are not yet saturated, promote the simultaneous development of geographical and virtual agglomeration, deepen the integration of digital technology and traditional advantageous industries, and amplify the economies of scale and synergistic effects of agglomeration. The western region should prioritize the development of digital infrastructure, rely on local characteristic resources, focus on developing virtual agglomeration to overcome geographical constraints, and cultivate new momentum for the development of the digital industry.

Third, strengthen the regional coordination mechanism and enhance spatial spillover effects. By clarifying the functional positioning and industrial division of labor between core and surrounding cities, policymakers should promote the formation of an industrial collaboration system with upstream and downstream coordination and horizontal complementarity. At the same time, with policy guidance and institutional innovation, they should break down administrative and market barriers to factor flows, promote the orderly flow and efficient allocation of core elements such as technology and talent among regions, and promote the formation of a high-quality regional economic pattern with complementary advantages and joint development.

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