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The impact of the digital economy on the structure of industrial agglomerations: data from 31 administrative regions of China

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Abstract. The problems of industrial agglomerations have been widely studied due to its important role in regional economic development. However, in the era of digital economy, due to its characteristic of ignoring geographical and spatial limitations, this phenomenon fundamentally challenges the traditional industrial agglomeration model. The relevance of this study is determined by the lack of research on the impact of the digital economy on the agglomeration of traditional manufacturing industries, especially in terms of regional heterogeneity and mechanism. Based on panel data of 31 provincial administrative regions in China from 2012 to 2022, this study uses an empirical model to analyze the impact of the digital economy on the level of industrial agglomeration in various provinces in China and deeply explores its mechanism and regional heterogeneity. The research results show that the development of the digital economy has significantly inhibited the agglomeration of traditional industries. Further, this inhibitory effect is weakened in regions with higher levels of economic development. As a key interaction term, the per capita GDP level directly affects the impact of the digital economy on industrial agglomeration. Further mechanism test results confirm that the digital economy can jointly affect industrial agglomeration through direct and indirect paths. As a key mediating variable, the digital economy can weaken industrial agglomeration through the "deindustrialization" path.

Keywords: industrial structure, regional polarization, spatial heterogeneity, digital transformation, agglomeration economies

Authors' contribution. Jin B. —– concept, collection and analysis of information, writing of the source text, final conclusions; Voskerichyan R.O. — scientific guidance, analysis of the collected information, revision of the text, final conclusions. All authors have read and agreed to the published version of the manuscript.

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Влияние цифровой экономики на структуру промышленных агломераций: данные по 31 административному району Китая

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Аннотация. Проблематика промышленных агломераций достаточно широко изучена в связи с ее важной ролью в региональном экономическом развитии. Однако цифровая экономика, характеризуемая игнорированием географических и пространственных ограничений, бросает фундаментальный вызов традиционной модели промышленной агломерации. Исследование основано на панельных данных по 31 административному району Китая за период с 2012 по 2022 г. Использована эмпирическая модель для анализа влияния цифровой экономики на уровень промышленных агломераций в различных провинциях Китая и подробно исследован их механизм и региональная неоднородность. Результаты исследования показали, что развитие цифровой экономики значительно замедлило рост агломераций традиционных отраслей промышленности. Кроме того, этот сдерживающий эффект ослабевает в регионах с более высоким уровнем экономического развития. Уровень ВВП на душу населения напрямую влияет на воздействие цифровой экономики на промышленную агломерацию. Дальнейшие результаты тестирования механизма подтверждают, что цифровая экономика может влиять на промышленную агломерацию прямым и косвенным образом. Являясь ключевой опосредующей переменной, цифровая экономика может ослабить промышленную агломерацию путем «деиндустриализации».

Ключевые слова: промышленная структура, региональная поляризация, пространственная неоднородность, цифровая трансформация, агломерационные экономики

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Introduction

Industrial agglomeration has garnered public attention as a critical factor in the expansion of regional economies. From the early textile industrial clusters in Britain to the Yangtze River Delta industrial clusters in contemporary China, industrial agglomeration has been rather important in advancing economic growth.

The emergence of the digital age and the evolution of digital information technology and digital economy might cause difficulties to the conventional industrial agglomeration model. Conventional industrial agglomeration theory underlines that the main factors influencing industrial location choice and spatial distribution are geographical proximity, knowledge spillovers and economies of scale (Krugman, 1992; Porter, 1998). With the information spread under the virtual network and platform economy, the digital economy has transcended time and geographical limits. Digital economic technology makes it feasible to maximize the area of resource allocation (Brynjolfsson et al., 2020). This may suppress industrial agglomeration effects, causing industries no longer concentrated in particular areas but progressively distributed in space.

Conversely, the growth of the digital economy could also somewhat intensify industrial agglomeration in particular areas. The existence of the digital divide might aggravate the disparity of regional development and generate regional polarization. Digital dividends, such as network effects and technological spillovers may strengthen the agglomeration advantages of leading regions (Forman, Goldfarb, Greenstein, 2012) and promote the concentration of high-skilled labor. The further concentration of knowledge-intensive industries in specific cities will intensify the polarization of “winner takes all”. The digital economy might generate more clear knowledge spillovers and magnify the technological advantages of some areas. Areas with better digital infrastructure could be more likely to draw businesses outside their boundaries to actively collect and widen regional imbalances.

Therefore, the effect of the digital economy on industrial agglomeration may present a complex duality, especially in nations with great geographical dimensions and significant regional economic differences where “regional inhibition” and “regional polarization” may coexist at the same time. From conventional industrial agglomerations, the industrial agglomeration and dispersion brought about by the digital economy may clearly differ in their evolutionary paths and agglomeration conditions; this difference may have a structural influence on the growth of regional economies.

Existing studies mostly concentrate on the knowledge spillovers and innovation-promoting effects of the digital economy itself (Peng, Lu, Wang, 2023; Audretsch, Feldman, 1996). The literature still debates the effect of the digital economy on industrial agglomeration. While some research highlights its agglomeration effects through network externalities, digital dividends like the innovation-driven capacity of the digital economy (Rochet, Tirole, 2003; Zhao, Weng, 2024), and knowledge spillovers (Delgado, Porter, Stern, 2014), others stress its dispersion effect by lowering geographical limits (Brynjolfsson et al., 2020). These studies mostly overlook two important problems:

1. Digitalization's conflicting function in the deindustrialization process. Digital technology could discourage conventional industrialization, therefore indirectly undermining agglomeration economies depending on industrial connections.
2. The moderating function of regional development level. High-GDP areas' capacity to absorb digital shocks — for example, via sophisticated infrastructure or skill reserves — can offset negative consequences, but this diversity is seldom measured.

This paper full in these gaps by theoretically and empirically examining the impact of the "digital suppression effect" on agglomeration based on data from 31 provincial-level administrative regions in China. The digital economy, we contend, not only directly attacks spatial agglomeration but also indirectly compromises it by hastening the outward movement of industrial structure away from conventional sectors. Importantly, we show how regional economic resilience (as indicated by GDP) offsets this suppression, therefore offering a complex justification for the different results in earlier studies.

This **study aims** to analyze the possible impact of the digital economy on the agglomeration of traditional industries and its deep-seated mechanisms, fill the gap in this field, and provide a reference for policymakers to formulate regional economic development strategies.

Theoretical of the impact of digital economy on industrial agglomeration: limitations and challenges

Traditional industry agglomeration theory. The theory of industrial agglomeration is rooted in the observation of economies of scale and geographical proximity. Marshall's (Marshall, 1890) external economic theory points out that industrial agglomeration can bring about labor market sharing, convenient supply of intermediate inputs, and knowledge spillover effects, thereby forming economies of scale. Weber's (Weber, 1909) location theory further analyzes the spatial agglomeration tendency of enterprises and emphasizes the importance of cost, labor and agglomeration effects. Krugman's new economic geography theory emphasizes the role of increasing returns to scale in industrial agglomeration, and believes that when the increasing returns to scale effect exceeds the transportation cost, industrial agglomeration will naturally occur.

These classical theories all imply a premise: the limitation of physical space leads to friction in the flow of factors. Geographical proximity largely determines the flow of production factors, logistics and knowledge. Therefore, traditional industrial agglomeration theory pays special attention to the impact of geographical proximity on the spatial distribution of industries.

The challenge of digital economy to traditional industrial agglomeration theory

The emergence of the digital economy has challenged traditional industrial agglomeration theory. The widespread use of digital technology reduces transaction costs, reduces information asymmetry, and breaks down physical boundaries, which may enhance increasing returns to scale. For instance, the advancement of platform companies like Alibaba and Amazon has allowed companies to mitigate search and transaction costs to a certain extent, thereby enhancing performance and accelerating innovation (Fang et al., 2022). According to Goldfarb & Tucker (Goldfarb, Tucker, 2019), the marginal replication cost of digital information is nearly zero, hence that knowledge distribution and resource allocation are no more entirely reliant on physical agglomeration. As a result, conventional industrial agglomeration theory may find it challenging to completely account for the network effects and virtual information features in the digital economy, and its static analysis framework may also find it challenging to capture the dynamic evolution of industrial agglomeration generated by the digital economy. Traditional industrial agglomeration may change into a “space-virtual” dual-dimensional agglomeration as this increased mobility allows for dimensional broadening and reconstruction of the spatial limits of industrial agglomeration (Wang et al., 2023; Chang, Zhang, Li, 2024; Zeng, Wu, Yuan, 2024).

The impact of digital economy on industrial agglomeration: mechanism, performance and heterogeneity. As an advanced economic form, the digital economy may have many impacts on industrial agglomeration. Existing research has found that the digital economy may weaken traditional agglomeration or promote new agglomeration.

Mechanisms by which the digital economy weakens traditional geographical agglomeration

Reducing transaction costs and information asymmetry. Charykova & Markov (Charykova, Markov, 2019) found that the digital economy can promote collaboration and innovation among enterprises and form regional agglomerations by reducing information costs and transaction costs. The popularity of digital platforms and the Internet has significantly reduced the costs of enterprise search, matching and transactions, making it easier for enterprises to obtain external information and resources, thereby reducing dependence on geographical proximity (Malone, Yates, Benjamin, 1987; Forman, 2005). Digital technology, such as internet business platforms. Allows consumers and suppliers to match more efficiently, greatly improving the efficiency of information acquisition. Reduces the potential transaction costs of both parties. At the same time, the high information mobility brought by the digital economy has reduced the impact of information asymmetry on market efficiency to a certain extent. Helps enterprises increase market share and optimize resource allocation efficiency (Brynjolfsson, Smith, 2000).

Promoting knowledge spillover. Rogers, Singhal & Quinlan (Rogers, Singhal, Quinlan, 2010) believe that Internet technology breaks the limitations of geographical space and improves the efficiency of knowledge and technology circulation. Digital technology enables knowledge spillover to be realized through online meetings, collaborative office software, cloud platforms, etc., thereby weakening the role of geographical proximity in knowledge dissemination (Audretsch, Feldman, 1996).

Expanding market scope. Digital platforms help companies expand their market scope. They expand the sales scope of products to the world. They also expand the scope of resource acquisition. This allows companies to better integrate into the global value chain and more easily reach a wider customer base, thereby reducing dependence on local markets (Gereffi, Humphrey, Sturgeon, 2005).

These mechanisms work together to make companies more flexible in location selection and no longer overly dependent on traditional geographical agglomeration areas. This may lead to the weakening of traditional industrial agglomeration.

Digital economy rises new agglomeration models. Although the digital economy may weaken traditional geographical agglomeration, it may also give rise to new agglomeration patterns. The theory of digital agglomeration may be based on the neo-Marshallian school. The buzz effect theory proposed by Storper & Venables (Storper, Venables, 2004) explains the logic of the generation of new agglomeration in the digital age. Storper believes that geographical proximity and non-trade interdependence shorten the cognitive distance between economic entities, thereby promoting the formation of "local buzz" through face-to-face communication. Promote local knowledge learning. The penetration of digital technology has caused a qualitative change in this mechanism: when the physical distance is weakened by virtual connection, high-frequency digital interaction can reconstruct "digital buzz". Digital technology has weakened the original concept of spatial proximity, and even if the physical distance is weakened, frequent virtual interactions can still produce innovation spillovers similar to geographical agglomeration.

This theoretical evolution has directly given rise to the practical form of digital industrial clusters. Digital clusters represented by science and technology parks, IT hubs, etc. are essentially the systematic embedding of the "digital buzz" effect into specific locations through digital infrastructure. For example, through 5G, Internet platforms, etc. These clusters are usually highly knowledge-intensive and innovative, attracting a large amount of talent, capital, and technological resources. Compared with traditional industrial clusters, digital clusters place more emphasis on the construction of innovation ecosystems and knowledge networks (Bresnahan, Gambardella, Saxenian, 2001). In areas with more complete digital infrastructure or knowledge networks, digital industrial clusters may lead to enhanced industrial agglomeration effects in specific areas.

The heterogeneity of digital economy's impact on industrial agglomeration. By lowering information asymmetries and knowledge spillover, the digital economy could influence the agglomeration of conventional industries. Simultaneously, it could also lead to digital industrial clusters. The influence of the digital economy on agglomeration might thus differ across several areas. Babkin et al. (Babkin et al., 2020) found that the influence of the digital economy on industrial agglomeration varies by area and that the local economic environment, policy support, and technological level influence industrial agglomeration in various areas. Digital infrastructure and talent resources, according to Fernandez-Escobedo & Cuevas-Vargas (Fernandez-Escobedo, Cuevas-Vargas, 2023), are major determinants influencing the agglomeration of digital industries. The digital economy could more readily encourage the creation of new agglomeration patterns in areas with total digital infrastructure and great digital skills. Furthermore, the digital transformation of the manufacturing sector is speeding up and might result in new spatial agglomeration patterns in the conventional manufacturing sector. This agglomeration is probably going to happen only in areas with strong economic development, complete infrastructure, and high urbanization rates (Chen, Guo, Xu, 2022). Thus, elements including the degree of regional economic growth are probably going to have indirect influence on industrial agglomeration.

Research Hypothesis

Based on the above literature review, this paper proposes the following research hypotheses:

H1: The development of the digital economy has a negative impact on the agglomeration of traditional industries.

H2: The digital economy affects the agglomeration of traditional industries through specific mediating variables.

H3: The impact of the digital economy on industrial agglomeration is spatially heterogeneous. In regions with higher economic development levels, complete digital infrastructure, and higher digital skills, the digital economy may be more likely to promote the formation of new agglomeration models.

Data and methodology

This paper aims to evaluate the impact of digital economy on the level of industrial agglomeration in various provinces of China. The main indicators include the digital economy level and industrial agglomeration level of 31 provincial administrative regions between 2012 and 2022. In order to avoid estimation bias caused by missing values, this study also adds control variables, including per capita GDP, population density, social consumption level, urbanization level, degree of openness to the outside world, R&D investment, higher education enrollment, and infrastructure level. Among them, the measurement of digital economy level is based on the entropy weight method proposed by (Liu, Yang, Zhang, 2020; Zhao et al., 2020) to calculate the provincial digital economy level. The level of industrial agglomeration is calculated based on the location entropy to measure the degree of industrial agglomeration in each province. The reason why this study uses the entropy weight method to measure the level of digital economy is as follow:

1. Digital economy covers multi-dimensional indicators such as infrastructure, industrial scale, and innovation capability. The entropy weight method can objectively reflect the degree of dispersion of each indicator through information entropy and avoid subjective weighting bias (Liu et al, 2020);
2. Some indicators in provincial data may have dimensional differences or nonlinear relationships. The entropy weight method effectively solves this

problem through standardization and entropy value calculation (Zhao, Zhang, Liang, 2020).

3. The digital economy level measurement index proposed by Liu & Zhao is a measurement index specifically developed for the development of China's digital economy based on 31 provinces in China. It has been widely used by Chinese scholars and is reliable. Although organizations such as the OECD also have indicators such as the digital economy index, they are often country-specific indicators and are suitable for measurement between countries.

Considering that the regions studied in this article and the data used are all provincial panel data in China, the digital economy level measurement index developed by Liu & Zhao is used.

In order to further reveal the possible regional heterogeneity, we divide China's 31 provinces into five major economic regions according to the level of economic development, namely Southeast, Northeast, Northwest, North, and Southwest.

Based on the five-point division suggested by Li Guoping, Dean of the Capital Development Institute of Peking University, the economic regional division approach (Li, Zhu, Sun, 2024). The traditional Chinese economic regional division method generally uses a four-point division (i.e., east, central, west, and northeast). But as the economy grows, regional disparities have grown and the regional economic growth disparity has shifted from east-west to north-south. The conventional division approach might not be enough to satisfy the needs for new economic forms and regional economic growth. Based on China's regional economic growth and geographical division traits, Li suggested a five-point division: southeast, northeast, north China, southwest, and northwest. It completely shows the consistency of nature and economy inside the area and the greatest variation between areas. The new division approach, meanwhile, is more consistent with China's natural geographic conditions and geographical landmarks including the Hu Huanyong Line, the Qinling-Huaihe north-south geographic division, and the inner and outer areas of the pass. Li's division approach also completely considers secondary geographical elements, the change of China's economic development model, the function of central cities and urban agglomerations, and the notable regional economic growth difference between the north and south of China. This division approach can more accurately show the issue of regional economic growth disparity between the north and south of China. For instance, the economy of the southeast region is quite advanced while the northeast and northwest areas lag behind in economic growth. At the same time, the five-region division has closer internal links than the conventional four-region split, which is helpful for economic connection and traffic organization. When researching developing economies like the digital economy, it is more rigorous. The provinces are divided as follow.

- Northeast: Liaoning, Jilin, Heilongjiang
- Northwest: Shannxi, Gansu, Ningxia, Xinjiang, Neimenggu, Xizang
- China North: Beijing, Tianjin, Hebei, Shanxi, Henan, Shandong
- Southwest: Chongqing, Sichuan, Guizhou, Yunnan, Guangxi, Qinghai

- Southeast: Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan

Among them, Southeast has the best level of economic development, including developed cities such as Guangzhou and Shanghai. Correspondingly, the economic development levels of Southwest and Northwest are relatively poor. In addition, the distance and size of the geospatial scope are also considered.

This paper mainly uses the panel fixed effect model to test the impact of the digital economy level on the level of industrial agglomeration, while controlling for time and space effects. The model is as follows:

$$Y_{it} = \alpha + \beta X_{it} + \mu_{it} + \lambda_{it} + \in_{it},$$

where Y_{it} represents the dependent variable of the i-th individual in period t; X_{it} represents the explanatory variable of the i-th individual in period t; μ_{it} represents individual fixed effects, which represent factors that are unique to each individual and do not change over time; λ_{it} represents time fixed effects, which represent factors that are unique to each time period and do not change with individuals; $\in_{it}$ represents the random error term; α represents a constant term; β represent the coefficients of the explanatory variables.

At the same time, the article also uses a mediating effect test model to deeply study the impact mechanism of digital economy on industrial agglomeration. The article also presents the spatial evolution characteristics and spatial heterogeneity of digital economy and industrial agglomeration from 2012 to 2022 through ArcGIS heat map and regional heterogeneity test.

Empirical analysis

Benchmark regression. Table 1 shows the results of the fixed effect model regression of provincial panel data. Columns 1 and 2 show the impact of the digital economy level on the provincial industrial agglomeration level. We added the core variable digital economy level in column 1, and then added a series of control variables in column 2. The final results show that the digital economy level will inhibit industrial agglomeration. When we control the digital economy level alone, the results still hold, and the coefficient does not change much. The results show that for every unit increase in the digital economy development level, the industrial agglomeration level will decrease by about 1.28 units. The digital economy development level and industrial agglomeration show a significant negative correlation. This may be because digital technology has the effect of improving production efficiency and reducing production costs. For the same production output, the labor and capital that may need to be invested in the digital economy environment are lower. At the same time, the intelligent manufacturing and platform economy brought by digital technology, especially the cross-border e-commerce platform, have promoted the development of small, medium and micro enterprises, which may further weaken the scale effect brought by agglomeration. The "small and fine" production model has replaced the traditional large-scale production, making the industry appear to be spatially discrete.

Table 1

Regression results of the panel two-way fixed effect model

Variables	Industry-Agg	Industry-Agg
Digi-eco	–1.287*	–1.280**
GDP-capita		0.598***
POPDens		0.762*
Social-Cons		–0.113
Urbanization		0.323
Foreign-T		–0.0351
Higher-EDU		–0.0734**
RD		0.0180
Infrastructure		–3.281**
Constant	–0.644**	–2.318
Observations	341	341
R-squared	0.064	0.314
Number of c	31	31

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

This trend is not uncommon in the current digital economy environment. The Internet and e-commerce platforms make production and sales easier and less dependent on traditional production and sales channels. It is estimated that the sales of global e-commerce platforms will reach 6 trillion US dollars in 2024, accounting for about 20% of the global retail market. The production and market transformation brought about by the digital economy is likely to further aggravate industrial dispersion. In addition, from the perspective of added value, the digitalization of the industrial chain has caused part of the added value to be included in non-industrial categories such as information transmission, software, and Internet services, which has further led to a decline in the marginal benefits of industrial agglomeration. The unique borderless characteristics of the digital economy have reduced the demand for traditional logistics, resources, markets, and labor. The infrastructure improvements brought about by the development of the digital economy have also enabled more non-traditional industrial areas to carry out industrial transfer, and the digitalization of information transmission channels has enabled innovation factors to spread more widely among regions. Under the combined effect of these influencing factors, the comparative advantages brought about by traditional industrial agglomeration will be significantly weakened.

In addition, we also noticed that the per capita GDP level in the control variables has a significant positive impact on industrial agglomeration, which means that there may be regional heterogeneity in regions with high economic development levels.

Robustness test. Table 2 shows the results of the robustness test. In this section, we conducted winsorization tests and replacement control variable tests. The first column of Table 2 is the result of the winsorization test. Due to the sample size limitation, this study aims to winsorize the data at the 10% level. After winsorize, the level of digital economy still has a significant negative impact on industrial agglomeration. The results are still robust.

Table 2

Regression results after replacing the control variables and winsorization test

Variables	Industry-Agg	Industry-Agg
Digi-eco	–1.374**	–2.928*
GDP-capita	0.605***	–1.692***
Labor-Force	2.847**	
Social-Cons	–0.116	–0.403**
Urbanization	0.411*	–0.244
Foreign-T	–0.0288	–0.361**
Labor-cap	–0.0740**	
RD	0.0192	0.165
Infrastructure	–3.109**	–4.375
POPDens		4.112*
Higher-EDU		0.0761***
Constant	–5.721	5.896
Observations	341	32
R-squared	0.317	0.898
Number of c	31	4

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

In order to further test the robustness of the model, we also conducted a replacement variable test. We consider that the regional labor force level is usually a key factor in analyzing industrial agglomeration, because the agglomeration of industries is largely to share between regions, or to attract labor to gather in order to reduce labor costs. Therefore, we introduced population density and the higher education enrollment into the original control variables to reflect the agglomeration economic effect and labor force level of the region. The employed labor force population data can also reflect the regional labor force level, so we replaced the population density with the employed labor force level (POPDens — LaborLevel). At the same time, we use labor capital to replace higher education enrollment (Labor-cap — Higher-EDU). The test results are shown in the second column. After replacing the control variables, the results are still robust.

Endogeneity test. In the empirical analysis, this paper acknowledges that the digital economy may have endogeneity problems, and the main reasons may include: reverse causality, omitted variable bias, and measurement error. The development of the digital economy may promote economic growth, but at the same time, economic growth may also promote the construction of digital infrastructure, forming a two-way causal relationship. In addition, the factors affecting the development of the digital economy may not be fully controlled. This causes omitted variables and may lead to estimation bias. Finally, there may be statistical errors in digital economic indicators, affecting the accuracy of the estimation. To alleviate the endogeneity problem, this study uses the instrumental variable method (two-stage least squares (2SLS/IV)). Through the two-stage regression test, we try to use instrumental variables to alleviate the endogeneity problem.

Instrumental variable = number of fixed telephones per 100 people in 1984 ×
× national information technology service revenue in the previous year

Considering that the digital economy relies on Internet technology, historical telecommunications infrastructure (such as fixed telephones) may be related to the development of the current digital economy. Because Internet technology is an extension of communication technology. The popularity of fixed-line phones may reflect the acceptance of communication technology and the level of infrastructure in the region, which may affect the subsequent application of digital technology.

The number of fixed-line phones in 1984 is a historical variable, which is far away from now (40 years) and is unlikely to directly affect current economic growth. Fixed-line phones were mainly used for communication in the 1980s, while the modern digital economy relies on the Internet, so the number of fixed-line phones in 1984 is unlikely to affect the economy through non-digital technology channels. At the same time, since the number of fixed-line phones in 1984 is a historical variable. Current economic growth will not affect the number of fixed-line phones in 1984, so the reverse causality problem can be ruled out. The exogeneity requirement of the instrumental variable is met.

In addition, the national information technology service income may reflect the level of overall technological development and is related to the current state of the digital economy. The addition of "national information technology service income" to the cross-product is a national-level variable, which may alleviate the problem of omitted variables at the regional level in some areas.

The results of the first-stage regression are shown in Table 3. Among them, the instrumental variable is statistically significant, proving that the instrumental variable is correlated with the endogenous variable. The Kleibergen-Paap LM test ($p = 0.0087$) rejected the null hypothesis that the instrumental variable is not identifiable, indicating that the model is identifiable. The Cragg-Donald Wald F statistic (17.10) is higher than the 10% critical value (16.38), proving that the instrumental variable is reliable.

Table 3

Regression result of the first-regression endogeneity test

Test Category	Statistic Name	Value	P-value	Critical Value (10%)	Conclusion
First Stage Regression	IV coefficient	7.59e–07	0.003	—	Significant
	F-statistic	9.12	0.0028	16.38	Pass
Identification Test	Kleibergen-Paap LM statistic	6.88	0.0087	—	Reject under identification
Weak IV Test	Cragg-Donald Wald F-statistic	17.10	—	16.38	Pass (10% level)

Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

Table 4 is the test result of the second-stage regression. After replacing the instrumental variables, the digital economy still has a significant negative effect coefficient on industrial agglomeration (–2.639). $R^2 = 0.966$, indicating that the model has strong explanatory power. The results are robust

Table 4

Regression result of the second-regression endogeneity test

Variables	Industry-Agg
Digi-eco	–2.639*
GDP-capita	0.602***
POPDens	0.708***
Social-Cons	–0.0749
Urbanization	0.310***
Foreign-T	–0.0356*
Higher-EDU	–0.0667***
RD	0.0352
Infrastructure	–3.466***
Constant	–2.475
Observations	341
R-squared	0.966
cdf	17.10

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

Mediation effect test

In order to further explore the mechanism of digital economy in inhibiting industrial agglomeration, we conducted a mediating effect test. We used the level of industrialization as the mediating variable, and the level of industrialization was measured by the ratio of industrial added value to regional GDP. The test results are shown in Table 5. The first column is the impact of the level of digital economy on the level of industrialization. The results show that the level of digital economy has a significant negative impact on the level of industrialization. This may be because the development of the digital economy has, to a certain extent, transferred the added value from pure industrial production to digital economic fields such as digital infrastructure services, reducing the level of regional industrialization. Relying on digital infrastructure, digital services may have better development in the region, leading to the redistribution of regional resources.

Table 5

Regression models examining the impact mechanism and reverse causation

Variables	Industrialization	Industry-Agg	Industry-Agg
Digi-eco	–1.766***		–1.287*
Industrialization		0.704***	
Constant	–1.962***	0.755***	–0.644**
Observations	341	341	341
R-squared	0.674	0.347	0.064
Number of c	31	31	31

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

At the same time, automation and digital technology have a substitution effect on traditional industries. Emerging technologies such as AI and robots will replace low-skilled labor in traditional manufacturing, reduce the dependence of traditional industrial sectors on labor, and lead to the shrinkage of labor-intensive industrial clusters. The rise of the platform economy allows enterprises to achieve collaboration across geographical regions, and digital information transmission also further reduces the demand for physical space agglomeration of enterprises, resulting in the shrinkage of industrial agglomeration.

In addition, the industrial structure changes brought about by the digital economy may also lead to a change in the form of industrial agglomeration. The borderless and physical-free projects, as well as financial technology and software spawned by the digital economy will promote the development of the service industry, and the speed is much faster than the development of the physical industry. The development of these digital service industries will lead to the redistribution of capital and labor, shifting away from traditional industries and weakening the proportion of traditional industries in the regional economy. Taking China as an example, the added value of China's tertiary industry in 2023 increased by 11.5% over the previous year, while the added value of the secondary industry only increased by 0.7%[1]. It can be found that the industrial structure transformation and substitution effect brought about by the digital economy are very obvious. On this basis, the decentralized function of the digital economy allows enterprises to no longer need to concentrate in traditional industrial areas, exacerbating the dispersion of industries.

The second column of Table 3 shows the impact of the level of industrialization on the level of industrial agglomeration. It can be seen that the level of industrialization has a significant stimulating effect on industrial agglomeration. This is also in line with the views of the new economic geography and factor endowment theory. As we mentioned at the beginning, the agglomeration of industries brings increasing returns to scale, and increasing returns to scale promote industrial development and further promote industrial agglomeration.

The last column of Table 3 is the direct effect of the digital economy on industrial agglomeration. After calculation, we can get the coefficient of the indirect effect is –1.243, the direct effect is –1.287, and the total effect is –2.53. From this, we can get that the mediating effect accounts for about 49% and the direct effect accounts for about 51%. The digital economy suppresses industrial agglomeration by suppressing traditional industrialization (49% path) and direct effect (51% path).

However, since it is a counterintuitive phenomenon that the digital economy reduces the level of industrialization, it is necessary to more rigorously evaluate its possible endogenous problems, such as reverse causality. At the same time, regions with low industrialization levels are also likely to develop digital industries more actively. In order to verify whether there is reverse causality between the two, we further conducted a reverse causality test. We used the lagged instrumental variable method and system GMM regression analysis (Generalized Method of Moments). Assuming that the level of industrialization may affect the development of the digital economy at the same time, we used the lagged term of the explanatory variable (digital economy) as an instrumental variable, and used the assumption that its historical value is unrelated to the current error term to separate the single impact of the digital economy on industry. If the verification is established, it proves that the past development of the digital economy may affect the current level of industrialization, but the current level of industrialization is unlikely to affect the past digital economy.

Reverse causality test. Furthermore, the level of industrialization may have path dependence, such as the previous level of industrialization will affect the current level. Then a simple lagged variable tool may not be enough to control the endogenous problem. Therefore, the system GMM analysis is cited. Combining the difference GMM and the level GMM, the lagged level and the difference level are used to control the cross-sectional and time dimensions of the panel data at the same time. This aim to reduce the dynamic panel bias to exclude the current interference. And provide more accurate research on the impact of the digital economy.

[1] In 2023, the added value of my country's “three new” economy will account for 17.73 % of GDP (www.gov.cn, 2024). Retrieved 7 February 2025 from https://www.gov.cn/lianbo/bumen/202407/content_6965271.htm

Table 6 is the result of the reverse causality test. The first and second columns are the results of the lagged instrumental variables and GMM analysis, respectively. The preliminary fixed effect model (as shown in Table 6) shows that the coefficient of the digital economy on the level of industrialization is –1.766, which has an inhibitory effect. The test results of the instrumental variable method show that the first-stage regression uses the digital economy with a lag of one period as the instrumental variable, with a coefficient of 0.738, and the result is significant. The Kleibergen-Paap F statistic is 301.82, indicating that the instrumental variable is strongly correlated with the endogenous variable, proving that the instrumental variable is reasonable. The coefficient of the digital economy in the second-stage regression is –2.471, which is still significantly negative, and the absolute value is greater than the result of the preliminary fixed effect model, indicating that after controlling the reverse causality, the negative effect of the digital economy is stronger. The test results of the GMM analysis show that the coefficient of the digital economy is –0.180, which is significant but the absolute value is reduced, which may be because the dynamic adjustment of the level of industrialization partially absorbs the long-term effect. From the results, the conclusions obtained by the instrumental variable method and GMM are consistent. Both methods show that the digital economy has a significant negative impact on the level of industrialization, and the effectiveness of the instrumental variables has passed the test, and the reverse causality does not hold (that is, the level of industrialization does not significantly lead to changes in the digital economy).

Table 6

Reverse causality Test-Lagged instrumental variables and system GMM regression analysis

Variables	Industry-Agg (IV–2SLS)	Industry-Agg (GMM)
Digi-eco	–2.471***	–0.180**
L.Industrialization-level		0.974***
Constant		–0.0982**
Observations	310	310
Kleibergen-Paap LM Cragg-Donald F	54.412*** 359.235	
Weak IV (10%)	16.38	
Hansen test	0.000	24.37
Number of c	31	31

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

Regional heterogeneity test. Considering that digital technology itself can become a new production factor, and the level of economic development has shown a positive impact on industrial agglomeration, different results may occur in regions with different levels of economic development. It is necessary to further explore possible spatial heterogeneity. In the process of research, we divided China's 31 provinces into five major economic regions, among which the southeast region has the highest level of economic development, while the southwest has the worst. Through the mean statistics Figure 1, it can be seen that between 2012 and 2022, the development of the digital economy and the level of industrial agglomeration in southeastern China showed an obvious nonlinear trend. The level of industrial agglomeration showed an approximately inverted U-shaped distribution, and there was a trend of rising again in 2021.

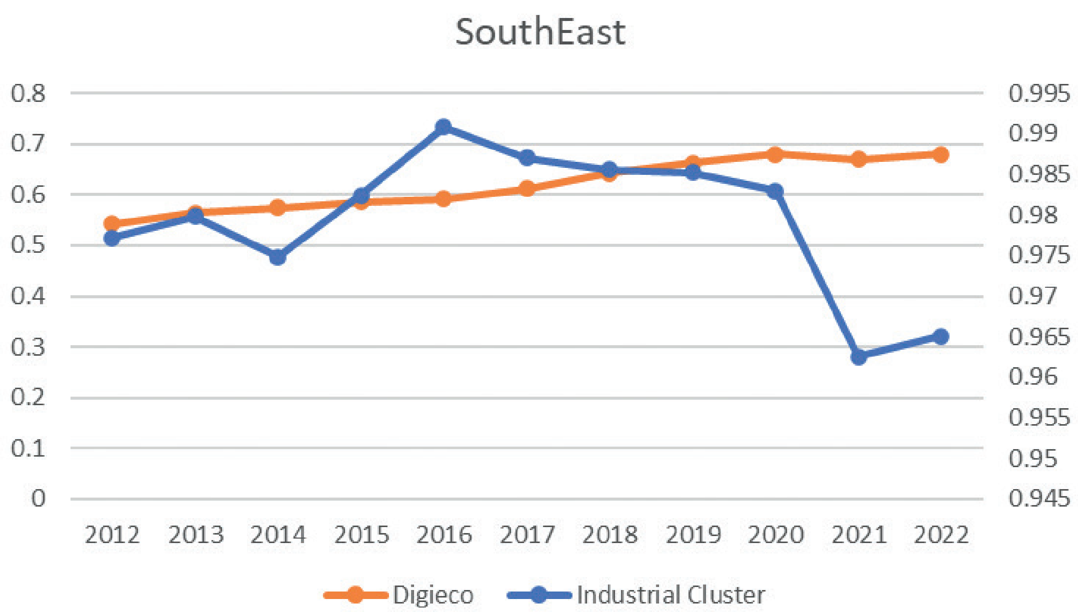

Figure 1. Industry Cluster & Digital Economy Southeast

Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

To further verify the possible spatial heterogeneity, we use GDP per capita as an interaction term for each of the five major economic regions. The test results are shown in the first column of Table 6, which show that in the southeast region, when the level of economic development is used as an interaction term, both GDP per capita and the interaction term are positive, which means that the weakening effect of the digital economy on industrial agglomeration will be suppressed in regions with high GDP per capita. A high level of economic development does make the impact of the digital economy less intense. To ensure the rigor of the study, we also conducted heterogeneity tests on other control variables that may be influencing factors. The second, third, and fourth columns of Table 7 are the results of using R&D investment, higher education level, and infrastructure level as interaction terms. The results are not significant. The regional heterogeneity in the southeast region is only affected by the GDP level.

Table 7

Regression models examining the regional heterogeneity-Southeast

Variables	Industry-Agg	Industry-Agg	Industry-Agg	Industry-Agg
Digi-eco	–16.19**	–0.0369	–0.627	–1.816
GDP-capita	1.022**	0.366	0.328	0.330
c. Digi-eco #c. GDP-capita	1.322**			
c. Digi-eco #c. RD		0.181		
c. Digi-eco #c. Higher-EDU			–0.00973	
c. Digi-eco #c. Infrastructure				0.503
POPDens	–0.0314	0.348	0.327	0.344
Social-Cons	–0.226	–0.197	–0.163	–0.162
Urbanization	1.497**	0.457	0.349*	0.288
Foreign-T	–0.0433	–0.119*	–0.116*	–0.124*
Higher-EDU	–0.0111	–0.0268	–0.0317	–0.0264
RD	0.165	0.186	0.0711	0.0743
Infrastructure	0.271	–2.868*	–3.797**	–3.410*
Constant	–11.67	1.283	3.727	2.637
Observations	121	121	121	121
R-squared	0.598	0.532	0.529	0.530
Number of c	11	11	11	11

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. STATA 17 is used as the calculation software.

This may be because the digital economy has a “destruction-reconstruction” effect on the agglomeration of traditional industries. The digital economy, especially during the transformation process, may indirectly reduce agglomeration by suppressing industrialization, but once the digital transformation is completed, new industrial agglomerations may be formed. Industries with digital production factors as the core may re-agglomerate based on shared digital infrastructure, high-skilled talents, government regional subsidies and other reasons. However, this re-agglomeration process may require the local economic development level to reach a certain level, which can withstand the industrial dispersion brought about by the digital economic transformation, and also have a large-scale digital economic foundation. China’s southeast region covers developed cities such as Guangzhou, Shenzhen, and Shanghai. Traditionally, this region has a large number of Internet industries and digital infrastructure. This may also be the reason for the re-agglomeration of industries in the southeast region.

Finally, through the visualization of the spatiotemporal evolution of industrial agglomeration and digitalization levels in 31 provinces from 2012 to 2022 (Figures 2, 3), we can see that in the southeast region, high digital economy and high agglomeration continue to coexist, which further verifies our speculation that regions with high levels of economic development may be able to overcome the weakening of industrial agglomeration effects brought about by the digital economy transformation more quickly and achieve new agglomeration.

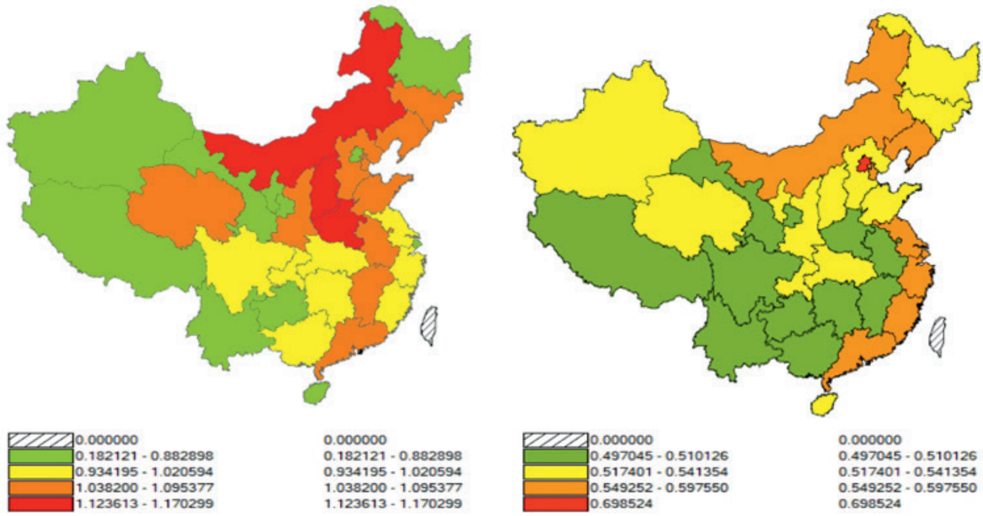

Figure 2. Industry Cluster & Digital Economy (2012)

Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. ArcGIS is used for drawing.

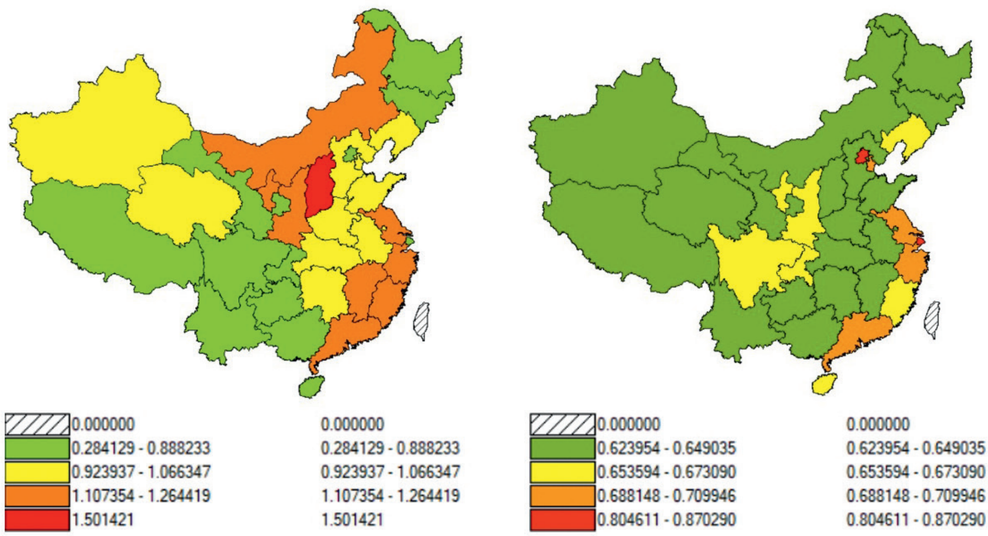

Figure 3. Industry Cluster & Digital Economy 2022

Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. ArcGIS is used for drawing.

Figure 4 is a heat map generated based on the data of digital economic development and industrial agglomeration. It can be seen that the industrial agglomeration in the southeast region has always shown high-value agglomeration from 2012 to 2022, that is, high-level digital economic development and industrial agglomeration phenomena appear simultaneously around the southeast region. This may be the polarization phenomenon in the process of digital economy reconstruction of industrial agglomeration. Digital economy industries themselves are more likely to be concentrated in areas with high levels of digital economic development in space

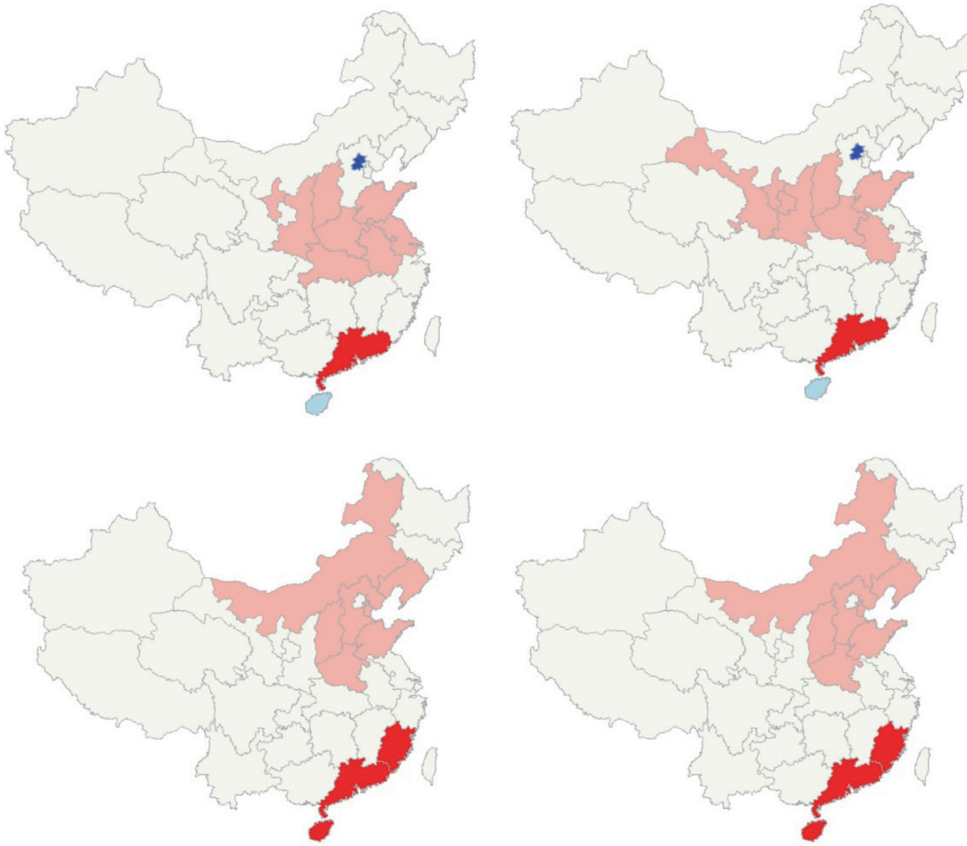

Figure 4. Industry Cluster & Digital Economy Hot Spot 2012–2022): The red area represents the high-value aggregation area, while the blue area represents the low-value aggregation area

Source: All raw data are from the National Bureau of Statistics of China. Data are collated and further calculated by B. Jin, R.O. Voskerichyan. ArcGIS is used for drawing.

Discussion

To support the transformation and upgrading of traditional industries, we propose the following specific measures:

1. Government-led technology empowerment: The government should take the lead in promoting the application of digital technology in traditional industries, for example, optimizing production processes through the Internet of Things and big data analysis, improving resource utilization, and reducing production costs. Government-led development can reduce uncertainty and strengthen the willingness of enterprises in this regard. The establishment of "Digital Economic Special Zones" by regional governments is more conducive to the agglomeration of related digital industries and promote regional economic development.

2. Platform construction: Accelerate the construction of industry cloud platforms to provide traditional enterprises with computing, storage, data analysis and other services required for digital transformation. Digital infrastructure plays a key role in promoting the development of the digital economy.

3. Talent cultivation: Governments and enterprises should work with universities to jointly carry out digital skills training for traditional industry practitioners, improve the quality of the workforce, and enhance their ability to adapt to the digital economy.

4. Policy subsidies: The government should formulate relevant policies to encourage traditional enterprises to increase investment in digital transformation, provide tax incentives, loan support, etc. For example, investing in digital economy equipment can provide tax discounts or shorten the depreciation cycle.

5. Avoid the single industrial structure: Actively cultivate emerging industries, expand industrial development space, form a diversified digital economy industry that matches local resource endowments, and enhance risk resistance.

6. Pay attention to regional development imbalances: Increase attention to regional development imbalances. Especially in areas with uneven development or underdeveloped regions, narrow the digital divide and avoid polarization of spatial agglomeration.

The digital economy may bring new opportunities for industrial agglomeration, but we cannot ignore the potential risks that may be caused by the digital economy's destruction of traditional industrial agglomeration forms, including unemployment, data security and regional development imbalances caused by industrial structure transformation. These risks should be closely monitored and corresponding countermeasures should be formulated to ensure the long-term vitality of regional economic development.

Conclusion

Although this study has analyzed the impact and mechanism of the digital economy on traditional industrial agglomeration in detail, there are the following limitations, which may affect the reliability and applicability of the results:

1. Data source limitations: All data are from China, and the research scope is limited to 31 provincial administrative regions. This means that the research results may be affected by China's specific economic, political and social environment, and caution is needed when directly generalizing to other countries and regions.

2. Depth of mechanism research: We mainly explored the impact mechanism of the digital economy on industrial agglomeration from the perspective of industrialization, and may have overlooked other important influencing factors, such as institutional environment and innovation capabilities. These mechanisms need to be studied more deeply in the future.

3. Lack of targeted analysis of other developing countries: The development speed of the digital economy in developing countries may exceed that of traditional industrialization, and there may even be developing countries that directly skip industrialization and enter the digital economy. Based on the Chinese context, this study failed to fully explore the impact of the digital economy on industrial agglomeration under this special background. Future research should focus on the specific conditions of developing countries, such as weak digital infrastructure and lack of digital skills, and explore corresponding policy recommendations.

Future research can expand the scope of research to other countries and regions to verify the universality of the conclusions of this study. In particular, attention should be paid to developing countries, and country-specific analysis should be carried out for specific situations. At the same time, more mechanisms of the digital economy affecting industrial agglomeration should be explored, such as innovation, institutional environment, etc. In addition, the heterogeneity and mechanism analysis results of the current research suggest that there may be a special threshold or threshold, that is, the nonlinear inflection point of the impact of the digital economy on industrial agglomeration. In the future, based on more data from developing countries, it may be possible to conduct in-depth exploration.

Our study shows that there may be a complex relationship between the digital economy and industrial agglomeration. Although from an overall perspective, the development of the digital economy may indirectly lead to the suppression of industrial agglomeration by suppressing industrialization, this relationship may be heterogeneous in economically developed regions. In regions with a high level of economic development and relatively complete digital infrastructure, the digital economy may optimize and reconstruct the industrial structure, thereby weakening or even eventually offsetting its negative impact on industrial agglomeration.

For policymakers, differentiated strategies need to be adopted in the process of considering the development of the digital economy. The impact of regional heterogeneity may cause a "one-size-fits-all" strategy to have unnecessary negative effects. In terms of policy recommendations, we emphasize that differentiated strategies should be adopted, and differentiated strategies should be formulated according to the industrial base and digital economic development level of different regions. For regions with weak industrial bases, attention should be paid to the integration of the digital economy and traditional industries to avoid the hollowing out of industries caused by excessive development of the virtual economy.

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