Measurement and Spatial Differentiation of Urban Innovation Capacity in the Yellow River Basin: Postprint

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Abstract

Innovation occupies a core position in the overall landscape of national modernization, cities serve as the principal regions for innovation activities, and scientifically measuring urban innovation capacity holds significant value for enhancing urban competitiveness and formulating innovation strategies. This study takes 48 cities in the Yellow River basin as the research object, constructs an urban innovation evaluation index system from four dimensions—talent cultivation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity—and employs data analysis methods including the entropy weight method, Jenks Natural Breaks classification, Gini coefficient, and Moran' s I to measure the innovation capacity of cities in the Yellow River basin and analyze the spatial differentiation of urban innovation levels and the main obstacle factors. The results indicate: (1) The overall innovation capacity of the Yellow River basin is not high, the score gap between a few high-value cities and the remaining cities is significant, and the innovation capacity exhibits a stepwise increasing trend from the upper, middle, to lower reaches. (2) With the Shuozhou-Longnan line as the boundary, urban innovation capacity exhibits a distribution pattern of high in the southeast and low in the northwest, and the spatial distribution of each dimension tends to be consistent with the overall innovation capacity. (3) The distribution of urban innovation capacity in the Yellow River basin is in a relatively unbalanced state, spatial agglomeration characteristics exhibit positive spatial autocorrelation, and it primarily manifests as a low-value agglomeration spatial pattern. (4) Scientific and technological R&D capacity and talent cultivation capacity exert substantial influence on the improvement of urban innovation capacity in the Yellow River basin, among which the number of effective inventions is a common obstacle indicator across cities.

Full Text

Measurement and Spatial Differentiation of Innovation Capacity of Cities in the Yellow River Basin

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Abstract: Innovation occupies a central position in the overall national modernization drive, and cities constitute the primary spatial units where innovation activities occur. Scientific measurement of urban innovation capacity is therefore critical for enhancing urban competitiveness and formulating innovation strategies. This study examines 48 cities within the Yellow River Basin region, constructing an urban innovation evaluation index system across four dimensions: talent cultivation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity. Employing the entropy weight method, Jenks natural breaks classification, Gini coefficient, Moran' s I index, and other analytical methods, we measured the innovation capacity of cities in the Yellow River Basin and analyzed the spatial differentiation of innovation levels and the main obstacle factors. The results indicate: (1) The overall innovation capacity of the Yellow River Basin is relatively low, with significant score gaps between a few high-value cities and the remaining cities, and innovation capacity demonstrates a stepwise increasing trend from upstream to midstream to downstream regions. (2) Using the Shuozhou-Longnan line as a boundary, urban innovation capacity exhibits a spatial pattern of high values in the southeast and low values in the northwest, with the spatial distribution of each dimension aligning with that of overall innovation capacity. (3) The distribution of urban innovation capacity in the Yellow River Basin is in a relatively unbalanced state, with spatial agglomeration characteristics showing positive spatial autocorrelation, primarily following a low-value agglomeration pattern. (4) Scientific and technological R&D capacity and talent cultivation capacity exert the greatest influence on improving urban innovation capacity in the Yellow River Basin, with the number of effective inventions being a common obstacle indicator across all cities.

Keywords: innovation capacity measurement; spatial differentiation; obstacle degree; Yellow River Basin

1 Introduction

Innovation is the primary driver leading economic and social development. As the spatial carriers of innovation activities, the key to measuring urban competitiveness lies in measuring their innovation capacity. The report of the 20th National Congress of the Communist Party of China explicitly states that innovation should remain at the core of China' s overall modernization drive. The Yellow River Basin represents a crucial ecological barrier and economic belt in

China, holding significant importance for the nation' s economic and social development as well as ecological security. The "Outline of the Plan for Ecological Protection and High-Quality Development of the Yellow River Basin" issued by the Central Committee of the Communist Party of China and the State Council in 2021 clearly points out the need to increase investment in scientific and technological innovation and enhance the capacity of scientific and technological innovation support in this region.

The urban innovation system was initially studied at the national level, after which research shifted to regional innovation systems. Scholars have continuously improved evaluation systems from empirical perspectives. From the perspective of agglomeration economies, James Simmie studied five typical European cities—Stuttgart, Milan, Amsterdam, Paris, and London—and identified five key elements: enterprise agglomeration, industrial agglomeration, scientist concentration, professional knowledge and technology, and external exchange. Charles Landry, in "The Creative City," more comprehensively proposed the basic capabilities for measuring urban innovation vitality, arguing that vitality is what a city needs to survive. Florida theoretically proposed the role of talent, technology, and tolerance in promoting innovative urban development.

Domestic scholars' evaluation indicator systems can be categorized into three types: First, from the input-output perspective, such as Fan Bonai et al., who measured and analyzed urban technological innovation capacity from five aspects: technological innovation input capacity, output capacity, allocation capacity, support capacity, and management capacity. Qiao Zhangfeng et al. constructed a measurement system for urban scientific and technological innovation capacity from four aspects: urban scientific and technological innovation input capacity, innovation output capacity, innovation environment support, and basic innovation support. Zhang Jianwei et al. focused on innovation output, using patent authorization quantity as a single indicator to represent innovation output and conducted spatial econometric analysis of county-level innovation output in Jiangsu Province. Second, from the perspective of innovation capacity components, such as Xie Kefan et al., who considered urban innovation capacity a comprehensive capability requiring support from urban economic foundations, social scientific research, education and culture, and technological environments. Ni Pengfei et al. constructed a structural equation model for urban innovation capacity, dividing indicators into exogenous and endogenous variables. Third, from the perspective of innovation capacity definition and innovation system function, such as Duan Lizhong et al., who used grey cluster analysis to summarize urban innovation capacity from five aspects: knowledge innovation capacity, technological innovation capacity, institutional innovation capacity, service innovation capacity, and macroeconomic innovation capacity. Zhang Lizhu et al. subdivided urban innovation capacity into four capabilities—knowledge innovation, technological innovation, government behavior, and service innovation —and established corresponding measurement indicators. Tao Xuefei measured urban innovation capacity from three dimensions: knowledge innovation capacity, technological innovation capacity, and innovation foundation.

Domestic scholars conducting such research often focus more on provincial capitals or coastal cities in eastern China where innovation levels are already relatively high, with less attention paid to cities in less developed regions, making it difficult to effectively support comprehensive innovation development across the country or region. The Yellow River Basin covers a vast territory spanning eastern, central, and western China, involving both developed and underdeveloped cities. Therefore, taking cities in the Yellow River Basin as the research object has reference significance for the innovation development of most cities nationwide.

2 Study Area and Methods

2.1 Study Area

The Yellow River flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong provinces from upstream to downstream. The population and GDP of these nine provinces account for 24.5% and 29.8% of the national total, respectively, holding important positions in China' s economic and social development. However, the ecological environment is fragile, with prominent contradictions among population, resources, and environment, and the overall development quality is not high. Based on the "Yellow River Yearbook," this study selects 75 prefecture-level administrative units as the scope of cities in the Yellow River Basin. Some autonomous prefectures and prefecture-level cities with severe data gaps were excluded, ultimately identifying 48 prefecture-level cities as the specific study area. Referring to the division of upper, middle, and lower reaches of the Yellow River water system, the upstream region extends from Xining to Guyuan, the midstream region from Hohhot to Linfen, and the downstream region from Zhengzhou to Heze.

Note: This map is based on the standard map downloaded from the National Geographic Information Public Service Platform with review number GS(2020)4630, with no modifications to the base map boundaries. The same applies below.

[Figure 1: see original paper] Schematic diagram of the Yellow River Basin

2.2 Data Sources

The primary data source is the "China City Statistical Yearbook," supplemented by statistical yearbooks from Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong provinces, official websites of municipal statistics bureaus, and 2020 national economic and social development statistical bulletins. Due to data deficiencies in some cities, data from adjacent years were used as substitutes where 2020 data were unavailable.

2.3 Research Methods

2.3.1 Construction of the Index System In an ideal situation, an evaluation index system should both cover all characteristics of the evaluation object and ensure complete linear independence among indicators. However, this ideal state is impossible to achieve in practice. Therefore, an excessive number of indicators increases the possibility of overlap, while too few indicators lead to one-sided measurement results. This study establishes a hierarchical structure of indicators to ensure independence between criteria layers and individual indicators, avoiding cross-correlation.

Through literature review, many scholars decompose evaluation index systems into knowledge, technology, economy, and environment dimensions based on definitions of innovation capacity. This study constructs a measurement system covering four dimensions—talent cultivation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity—with 20 specific indicators. Talent cultivation capacity is fundamental to innovation capacity, scientific and technological R&D capacity is the core, and economic support capacity and environmental service capacity are indispensable basic elements. Specific indicators are shown in Table 1.

Indicator system for measuring urban innovation capacity

2.3.2 Entropy Weight Method Commonly used dimensionless processing methods include Z-score, range standardization, and vector normalization. Different methods have different applicable scopes and must be selected based on data characteristics and research objectives. This study uses the entropy weight method to assign weights to evaluation indicators. Referring to Zhu Xi' an' s discussion on dimensionless methods in the entropy weight method, range standardization is considered more applicable in practical application than other methods. Therefore, range standardization is selected to eliminate dimensions using the following formula:

$$x'_{ij} = \frac{x_{ij} - m_j}{M_j - m_j}$$

where x'_{ij} is the standardized value of indicator j for city i; x_{ij} is the original value of indicator j for city i; M_j is the maximum value of indicator j; and m_j is the minimum value of indicator j.

To minimize both subjective influence in the weight determination process and objective influence among indicators, this study employs the entropy weight method to assign weights to each evaluation indicator (Table 1). Its advantage lies in avoiding interference from subjective factors and using the importance degree of indicators as the basis for weighting. In the constructed indicator data matrix, the smaller the data dispersion, the larger the entropy value, the smaller the information provided, and thus the smaller the impact of that indicator on the overall evaluation and its corresponding weight; conversely, the weight is larger.

2.3.3 Obstacle Degree Model To identify key factors limiting the further improvement of urban innovation capacity in the Yellow River Basin, the obstacle degree model is used. The degree of influence of obstacle factors is determined through the magnitude of obstacle degrees. The specific calculation formulas are:

$$O_{ij} = \frac{F_j \times D_{ij}}{\sum_{j=1}^{m} F_j \times D_{ij}} \times 100\%$$

$$V_{ij} = \sum_{j=1}^{n} O_{ij}$$

where O_{ij} is the obstacle degree at the indicator level; F_j is the weight of individual indicator j to the total objective, obtained by summing the weights of its constituent indicators; D_{ij} is the deviation degree of indicator j, representing the gap between individual indicator j and the total evaluation objective, calculated as $D_{ij} = 1 - x'_{ij}$; and V_{ij} is the obstacle degree of criterion layer i to urban innovation capacity.

2.3.4 Gini Coefficient The Gini coefficient is used to scientifically and quantitatively measure the degree of difference in innovation capacity among cities. It can directly reflect the inequality of regional innovation levels. The formula is:

$$G = \frac{1}{2n^2 \bar{U}} \sum_{i=1}^{n} \sum_{j=1}^{n} |U_i - U_j|$$

where n is the total number of cities; U_i and U_j are the innovation capacity composite scores of any two evaluated cities; and $\bar{U}$ is the average value of urban innovation capacity composite scores.

2.3.5 Moran' s I Index To measure the spatial agglomeration state of urban innovation capacity in the Yellow River Basin, the concept of Moran' s I is introduced. Moran' s I and Geary' s C are both global indicators for measuring spatial autocorrelation, and there is a negative correlation between them. Referring to Griffith' s proposed application simulation experiments, both can basically substitute for each other. Comparatively, Moran' s I is more robust and less likely to deviate from normal distribution, so this study selects the more applicable Moran' s I. The calculation formula is:

$$\text{Moran's I} = \frac{n\sum_{i=1}^{n}\sum_{p=1}^{n} W_{ip}(U_i - \bar{U})(U_p - \bar{U})}{S\sum_{i=1}^{n}(U_i - \bar{U})^2}$$

where U_i and U_p are the observed values of regions i and p; W_{ip} is the spatial weight value between cities i and p; and S is the aggregation of all spatial weights.

3 Results and Analysis

3.1 Urban Innovation Capacity Scores

Based on the entropy weight method, the weights of evaluation indicators for urban innovation capacity in the Yellow River Basin were calculated, and the innovation capacity scores of 48 cities were further computed, along with scores for the four dimensions: talent cultivation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity. The results are shown in Table 2.

The average comprehensive innovation capacity score of 48 cities in the Yellow River Basin is 0.176. Xi' an ranks first with a score of 0.654, while Longnan ranks last with a score of 0.027. The average is skewed toward the scores of low-value cities. For cities in the Yellow River Basin, the overall innovation capacity is not high, with a large number of low-value cities pulling down the overall score, indicating a polarization phenomenon. The possible reasons lie in the contradictions between population and resources, difficulties in industrial upgrading and transformation, and slow high-quality development processes in the Yellow River Basin itself. Moreover, provincial capitals such as Xi' an and Zhengzhou are currently in a stage where polarization effects exceed trickle-down effects, with various production factors moving toward developed cities coupled with policy biases, creating a polarization phenomenon.

Specifically, Xi' an, Zhengzhou, and Jinan have relatively strong innovation capacities with scores of 0.654, 0.484, and 0.376, respectively, showing large gaps with other cities. The remaining cities are in a low-level equilibrium state. Longnan, Ulanqab, and Qingyang rank in the bottom three with weak innovation capacities. At the dimensional level, the ranking of the four dimensions largely matches the order of overall urban innovation capacity. In talent cultivation capacity, Xi' an and Zhengzhou are far above the average, which is closely related to the distribution of higher education faculty resources, as most universities and research institutes are concentrated in provincial capitals. In scientific and technological R&D capacity, Xi' an, Zhengzhou, and Jinan still rank top three, with huge gaps from other cities. In economic support capacity, Zhengzhou and Xi' an rank first and second, indicating that these two cities have solid economic foundations, especially Zhengzhou, which can provide sufficient financial support for innovation activities. In environmental service capacity, Zhengzhou and Xi' an perform well, while Linyi notably rises to third place, demonstrating that as a central city in southeastern Shandong, Linyi has promising innovation development prospects.

To better understand the overall situation of urban innovation capacity in different reaches of the Yellow River Basin, the study area is divided into upstream, midstream, and downstream regions for comparative analysis using average scores of each region (Figure 2).

[Figure 2: see original paper] Comparison of innovation capacity and dimensions of cities in subsections of the Yellow River Basin

Overall, the average comprehensive innovation capacity score is 0.104 for upstream cities, 0.162 for midstream cities, and 0.264 for downstream cities, indicating that innovation capacity in the Yellow River Basin shows a stepwise increasing trend from upstream to midstream to downstream regions, with considerable gaps between downstream and upstream cities. This aligns with Zeng Gang et al.' s findings that most cities in the Yellow River Basin have lower technological innovation capacity, with technological innovation continuously diffusing spatially and invention patents in midstream and downstream cities having formed agglomerations. The possible reasons for this stepwise increasing trend lie in the fragile ecological environment and weak industrial competitiveness of upstream cities, while downstream regions have solid economic foundations and benefit significantly from the development of the Central Plains Urban Agglomeration and Shandong Peninsula Urban Agglomeration, showing notable siphon effects.

At the dimensional level, Figure 2 clearly shows that downstream cities have higher scores in all four dimensions, while upstream cities have the lowest scores, consistent with the stepwise increasing trend of overall urban innovation capacity. In talent cultivation capacity, cities in midstream and upstream regions show little difference, with upstream cities not falling significantly behind in talent cultivation. In scientific and technological R&D capacity, upstream cities lag most significantly behind downstream cities, with this huge gap revealing the weakness of upstream cities in technological innovation and the uncoordinated distribution of innovation resources. In economic support capacity, downstream cities have good financial support, while upstream cities show corresponding weaknesses. In environmental service capacity, a similar stepwise increasing trend is observed, but with smaller differences among cities, indicating that the overall innovation foundation environment in the Yellow River Basin is good, providing a sound environmental basis for innovation activities.

3.2 Spatial Distribution Pattern of Urban Innovation Capacity

To intuitively analyze the spatial distribution pattern of urban innovation capacity in the Yellow River Basin, this study uses ArcGIS' s Jenks natural breaks classification function to classify the comprehensive innovation capacity scores of 48 cities in 2020, dividing them into five types: low-level, relatively low-level, medium-level, relatively high-level, and high-level areas (Figure 3).

[Figure 3: see original paper] Spatial distribution of innovation capacity of cities in the Yellow River Basin

Figure 3 shows that the overall spatial distribution of urban innovation capacity roughly follows the Shuozhou-Longnan line, presenting a spatial differentiation pattern of high values in the southeast and low values in the northwest. Shandong, Henan, Shanxi, and Shaanxi provinces have relatively high overall innovation levels, with cities surrounding high-value cities like Zhengzhou, Jinan, and Xi'an also having relatively high innovation levels. In contrast, the northwestern region generally has low innovation levels, and the radiation and driving effects of high-value cities on surrounding cities are not strong. For example, Lanzhou in Gansu Province has relatively strong independent innovation development capacity, while neighboring Baiyin and Wuwei are low-level innovation capacity areas.

From the perspective of talent cultivation capacity, educational resource investment is generally concentrated in provincial capitals, and the capacity for talent to be delivered from central cities outward is relatively low. In the spatial distribution of scientific and technological R&D capacity, the southeast-high northwest-low differentiation phenomenon is more significant, with innovation resources clearly concentrated in economically developed Shandong, Henan, Shanxi, and Shaanxi provinces, while northwestern regions like Gansu and Ningxia do not pay sufficient attention to scientific and technological R&D. In economic support capacity, a notable increase in the number of high-value cities can be observed, with some central region cities like Hohhot, Baotou, and Ordos having good economic support capacity for innovation development. In environmental service capacity, the number of high-value cities decreases compared to economic support capacity, but there is still an east-to-west migration of high-value city distribution, indicating that relatively backward central and western cities have considerable innovation development prospects and a sound environmental foundation for innovation activities.

[Figure 4: see original paper] Spatial distribution of cities in the Yellow River Basin by dimension of innovation capacity

3.3 Spatial Differentiation and Agglomeration Characteristics of Urban Innovation Capacity

This study uses the Gini coefficient to determine spatial differentiation characteristics of urban innovation capacity in the Yellow River Basin. The calculated Gini coefficient is 0.423. With a G value between 0.4 and 0.5, the gap in innovation capacity among cities in the Yellow River Basin is relatively large, confirming the huge numerical differences and spatial differentiation patterns of urban innovation capacity shown in the tables and figures above.

In terms of agglomeration characteristics, this study uses Moran' s I to analyze the spatial autocorrelation status of urban innovation capacity in 48 cities of the Yellow River Basin in 2020 and draws Moran scatter plots for overall innovation capacity and each dimension. The Z-value for talent cultivation capacity did not pass the significance test, showing random spatial distribution. The Z-values for overall urban innovation capacity and the other three dimensions all passed significance tests, with values of 2.871, 2.793, 2.664, and 2.853, respectively. Positive and significant Z-values indicate positive spatial autocorrelation in innovation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity, with similar observed values tending to cluster spatially.

[Figure 5: see original paper] Moran' s I scatterplot of innovation capacity and sub-dimension of cities in the Yellow River Basin

Examining overall urban innovation capacity first, sample points are distributed across all four quadrants, with the most and densest points in the third quadrant, followed by the first quadrant. This indicates that the spatial autocorrelation pattern among cities is primarily low-low agglomeration, followed by high-high agglomeration. The dense distribution of points in the third quadrant of the scatter plot shows a very obvious agglomeration characteristic. At the dimensional level, scientific and technological R&D capacity, economic support capacity, and environmental service capacity all show consistent positive agglomeration characteristics with overall urban innovation capacity, with sample points distributed across all four quadrants. The number of low-low agglomeration type cities in the third quadrant is the largest, belonging to a low-value agglomeration spatial pattern.

Further local spatial autocorrelation analysis (Figure 6) shows that overall, the spatial association types of urban innovation capacity are dominated by significant low-low areas, which are contiguously distributed in space and most numerous, concentrated in the midstream and upstream regions. Cities with relatively low innovation capacity—Longnan, Tianshui, Pingliang, Qingyang, Guyuan, and Yulin—tend to cluster spatially. In contrast, there is only one significant high-high area: Zibo in Shandong Province. The innovation capacity of cities in the Yellow River Basin belongs to a low-value agglomeration spatial pattern. The distribution of reverse association areas is relatively dispersed, with high-value cities surrounded by low values including Lanzhou and Taiyuan, and low-value cities surrounded by high values including Jiaozuo and Kaifeng. For these regions, cities should avoid excessive polarization that causes regional development imbalances.

[Figure 6: see original paper] LISA distribution of innovation capacity and subdimensions of cities in the Yellow River Basin

At the dimensional level, upstream regions are dominated by significant low-low areas, consistent with the distribution map of overall innovation capacity. Downstream regions show high-high agglomeration, while midstream and upstream regions show low-low agglomeration, indicating that upstream regions have formed strong siphon effects and that well-developed cities can drive surrounding cities to develop and form clusters. The reverse association areas of the four dimensions are relatively dispersed and few in number, mainly consisting of high-value cities surrounded by low values.

3.4 Analysis of Main Obstacle Factors for Urban Innovation Capacity

This study uses the obstacle degree model to calculate the obstacle degrees of various indicators for 48 cities in the Yellow River Basin, with the top five indicators considered as main obstacle factors (Table 3). Overall, main obstacle factors show consistency, while different cities have their particular obstacle factors. The top five average obstacle degrees at the indicator level are: number of effective inventions (13.45%), public library collection (8.92%), export value (8.76%), internal expenditure of R&D funds (8.35%), and import value (7.94%). The segmented average rankings for upstream, midstream, and downstream regions are consistent with the overall ranking.

Main obstacles and degree of obstacles to the innovation capacity of cities in the Yellow River Basin

The number of effective inventions has a relatively strong impact on the development of urban innovation capacity in the Yellow River Basin. The number of effective inventions refers to the quantity of invention patents maintained during the statistical period, reflecting whether innovation activities are active. For the Yellow River Basin, the imbalance in invention capacity among regions is a key factor hindering the improvement of overall innovation capacity. The average obstacle degree ranking at the criterion layer is: scientific and technological R&D capacity (40.69%) > talent cultivation capacity (33.75%) > environmental service capacity > economic support capacity. Among them, scientific and technological R&D capacity is consistently the primary obstacle factor, and talent cultivation capacity is the secondary obstacle factor. Scientific and technological innovation and talent cultivation should become the focus for enhancing urban innovation capacity in the Yellow River Basin.

4 Discussion and Conclusions

4.1 Discussion

This study examines how to measure the overall level of urban innovation in the Yellow River Basin and explores its internal spatial differentiation, agglomeration characteristics, and main influencing factors. Compared with previously published literature, Xue Baoqi used patent authorization data to measure urban innovation capacity in the Yellow River Basin, and the spatial differentiation results and agglomeration characteristics are consistent with this study. Ren Guixiu et al. used green patent data to represent green innovation levels in Yellow River Basin cities, and their spatial autocorrelation results are also consistent with this study. However, the key innovation of this research lies in constructing an urban innovation capacity measurement system from four dimensions—talent cultivation capacity, scientific and technological R&D capacity, economic support capacity, and environmental service capacity—and conducting comprehensive and dimensional evaluations of cities in the Yellow River Basin.

It should be noted that this study only reflects the innovation development status of the Yellow River Basin in 2020 and does not involve changes in innovation development levels over continuous time periods. Moreover, this research only analyzes the internal spatial pattern of the Yellow River Basin, lacking comparative studies with other basins. Analyzing the dynamic evolution characteristics of urban innovation capacity in the Yellow River Basin and its gaps with cities in the Yangtze River Basin and Huaihe River Basin remains a direction for future research.

4.2 Conclusions

1. **Innovation Capacity Scores**: Urban innovation capacity in the Yellow River Basin shows a stepwise increasing trend from upstream to midstream to downstream regions, with significant gaps between provincial capitals and other cities. Based on the innovation capacity development levels, most cities in the Yellow River Basin have not yet reached the stage where scientific and technological innovation becomes the core driver of high-quality economic and social development.
2. **Spatial Distribution Patterns**: Urban innovation capacity in the Yellow River Basin exhibits a significant differentiation characteristic of high values in the southeast and low values in the northwest. High-value agglomeration areas have formed in the southeast, while the northwest generally has weak innovation capacity. Moreover, the driving effect of a few high-value cities on surrounding cities is not obvious, with polarization effects significantly exceeding trickle-down effects, and various human and technological resources tend to flow toward high-value cities.
3. **Spatial Differentiation and Agglomeration Characteristics**: The distribution of urban innovation capacity is in a relatively unbalanced state, showing positive spatial autocorrelation but primarily following a low-value agglomeration pattern. The number of low-low agglomeration type cities far exceeds that of high-high agglomeration type cities, with low-low areas mainly concentrated in midstream and upstream regions. The uncoordinated distribution of innovation resources will inevitably hinder the high-quality development of cities in the Yellow River Basin.
4. **Main Obstacle Factors**: Scientific and technological R&D capacity and talent cultivation capacity are the primary and secondary obstacle factors affecting the improvement of urban innovation capacity in the Yellow River Basin. The number of effective inventions is a common obstacle indicator for all cities. Therefore, downstream regions should focus on scientific and technological R&D, midstream regions should play a bridging role, and upstream regions should emphasize talent cultivation and infrastructure construction.

4.3 Policy Recommendations

1. **For Underdeveloped Upstream Regions**: The focus should be on talent cultivation and improving environmental service capacity. For these economically backward cities, innovation capacity can be enhanced through talent cultivation, introduction, and urban environment improvement. Specifically, they should emphasize investment in educational resources, improve education coverage, utilize higher education resources to cultivate needed technical talents, and strengthen the attraction of high-quality innovative talents. Governments should implement a series of talent introduction measures and increase support for upstream regions to address the imbalance in educational resource allocation. Simultaneously, they should continuously improve infrastructure construction, enhance supporting conditions in transportation, logistics, and production services, and improve overall urban environmental service capacity. Industrial transfer from midstream and downstream regions to upstream regions provides good development opportunities for upstream cities.

2. **For Midstream Regions**: They should play a bridging role to connect upstream and downstream cities and narrow gaps for coordinated development. The innovation capacity distribution in the Yellow River Basin is relatively unbalanced with significant spatial differences—high in the southeast and low in the northwest, strong downstream and weak upstream—and the spatial association pattern is dominated by low-low agglomeration type cities. Underdeveloped regions with low development levels receive correspondingly fewer resources. This pattern of imbalanced innovation capacity development in the Yellow River Basin should not be solidified. Midstream cities should leverage their location advantages to continuously play a bridging role, establish well-connected urban transportation networks linking upstream and downstream cities, and utilize the driving effect of downstream regions to coordinate innovation capacity development across the entire Yellow River Basin.

3. **For Well-Developed Downstream Regions**: Enterprises should continuously improve their independent innovation capacity and deliver advanced technology, talent, and ideas to upstream regions. For strong enterprises in these regions to achieve long-term sustainable development without being eliminated by the times, they need to continuously conduct scientific and technological innovation and focus on scientific and technological R&D capacity as the main carrier of scientific and technological innovation. Therefore, effective measures should be taken to increase investment in scientific research funds and technological talents in enterprises across various cities, such as government support for enterprise R&D funding and a series of tax incentives, to guide enterprises to attach importance to scientific and technological innovation, strengthen their autonomy in scientific and technological R&D, and form innovation awareness.

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Note: Figure translations are in progress. See original paper for figures.