Spatiotemporal Evolution, Spatial Correlation and Difference Decomposition: A Study on the Evolution Law of Innovation Ecosystem in Western China

Hanrui Li[1, a], Xiyue Luo[1, b], Hao Lin[2, c], Ruiyan Zhu[2, d], Aiqi Luo[1, e], Jinyang Liu[1*]

[1]School of Statistics, Chengdu University of Information Technology, Chengdu, 610225, China
[2]School of Management, Chengdu University of Information Technology, Chengdu 610225, China
Hanrui Li and Xiyue Luo are the co-first authors

[a]1738001798@qq.com, [b]2197354268@qq.com
[c]1656792498@qq.com, [d]331513159@qq.com
[e]3309485584@qq.com
*Corresponding author: lista@ciut.edu.cn

Abstract. Taking 12 provinces in western China as research objects, this paper constructs a regional innovation ecosystem index using the DP2 method based on 2014–2023 panel data. It integrates hierarchical standard deviational ellipses, exploratory spatial data analysis, K-Means optimized nested Theil decomposition, and gravity center model to reveal spatiotemporal evolutionary patterns. Results show a significant core–periphery structure with innovation resources concentrated in Sichuan, Shaanxi, and Chongqing. Spatial agglomeration strengthens continuously; hotspots shift from Chongqing–Shaanxi to a stable Chongqing–Guizhou corridor, and Xinjiang persists as a cold spot. The innovation index grows steadily, and regional differences first expand then converge, mainly arising from intra-provincial imbalance rather than geographic divisions. The gravity center moves northwest, southwest, and then stabilizes, covering three development stages. Robustness tests verify the reliability of conclusions. This study supports innovation ecosystem optimization and regional collaborative innovation in western China.

Keywords: innovation ecosystem; spatial-temporal evolution; spatial correlation; gravity center migration; western China

1 Introduction

1.1 Research Background and Significance

Against the background of the in-depth implementation of the innovation-driven development strategy and the accelerated advancement of the new-era western development strategy, the innovation ecosystem has become a key carrier for enhancing regional core competitiveness and fostering new-quality productivity[2]. Western Chi-

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na is characterized by relatively weak innovation foundations, uneven spatial distribution of innovation resources, significant regional development gaps, and insufficient cross-regional innovation linkages[7]. Scientifically identifying the spatiotemporal evolutionary laws, spatial correlation structure, and difference sources of innovation ecosystems in western China is of great theoretical value and practical significance for optimizing the spatial allocation of innovation resources, promoting coordinated regional innovation development, and narrowing internal development gaps.

1.2 Research Content and Framework

Taking 12 provinces in western China as analysis units, this paper adopts multiple spatial statistical methods to systematically analyze the evolutionary laws of innovation ecosystems from six aspects: spatial pattern, spatial correlation, temporal evolution, difference decomposition, gravity center change, and robustness test. A complete spatiotemporal analysis framework is formed to remedy the problems of insufficient attention and single method in existing studies on western China.

2 Research Design and Data Processing

2.1 Research Scope and Data Sources

Taking 12 provinces in western China as research units, this paper comprehensively applies various spatial statistical and time-series analysis methods to explore the dynamic evolutionary laws of innovation ecosystems in western China from six dimensions: spatial pattern, spatial correlation structure, temporal evolution trend, regional difference decomposition, gravity center migration characteristics, and robustness test. A complete spatiotemporal analysis framework is constructed to make up for the lack of pertinence and relatively single research method in existing studies, so as to provide scientific basis and decision reference for regional innovation ecosystem construction[3].

2.2 Core Methods and Variable Design

This paper employs the DP2 method to synthesize the regional innovation ecosystem index as the core dependent variable. This approach efficiently processes multi-dimensional nonlinear data and enhances result robustness via objective weighting[7]. Research methods include hierarchical standard deviational ellipses, global spatial autocorrelation, LISA clustering, K-Means optimized nested Theil decomposition, and gravity center migration modeling. The Bai–Perron multiple structural break test is used for stage division with a maximum of 2 breakpoints, determined by BIC and supF tests ($p<0.05$), enabling refined spatial-temporal analysis[6].

3 Spatial Pattern Evolution of Innovation Ecosystem in Western China

3.1 Spatial Pattern Analysis of Standard Deviational Ellipse

To identify spatial agglomeration differences of different innovation factors, based on the quadruple helix structure of the innovation ecosystem, this paper divides the system into four dimensions: innovation subjects, innovation input, innovation output, and innovation environment[1], and conducts hierarchical standard deviational ellipse calculations to distinguish spatial clustering characteristics of different innovation factors. On this basis, this paper presents the standard deviational ellipse results of the comprehensive innovation ecosystem index. From 2014 to 2023, the innovation ecosystem ellipse in western China always covers Sichuan, Shaanxi, and Chongqing, presenting a typical core–periphery spatial structure[2]. As shown in Table 1, the major axis first contracts then expands, indicating that innovation resources first agglomerate then spill over slightly. The minor axis continuously shrinks, indicating strengthened innovation agglomeration in the north–south direction. The rotation angle gradually decreases and the flatness ratio declines, so the spatial shape evolves from "east–west narrow" to "nearly circular", and regional innovation balance improves steadily. Hierarchical verification shows that innovation output and subjects present stronger spatial agglomeration than innovation environment and input, which confirms the effectiveness of hierarchical analysis[1].

Table 1. Parameters of Standard Deviational Ellipses and Gravity Centers for the Comprehensive Innovation Ecosystem Index in Western China (2014–2023).

Time Node	Major Axis Length (km)	Minor Axis Length (km)	Rotation Angle (°)	Oblateness	Central Longitude (°E)	Central Latitude (°N)
2014	921.19	822.28	165.49	0.893	106.3	31.6
2017	918.28	725.17	169.32	0.790	107.2	32.3
2020	910.93	753.83	158.48	0.828	105.9	30.9
2023	958.98	789.83	151.80	0.824	106.1	31.1

3.2 Migration Track of Innovation Ecological Gravity Center

The gravity center of the innovation ecosystem in western China always fluctuates around the Sichuan–Chongqing region, and the overall migration trajectory presents a clear three-stage characteristic of "northwest → southwest → stable optimization" (Figure 1). From 2014 to 2017, the gravity center moved northwestward, mainly driven by the implementation of the Belt and Road Initiative and the rapid increase of innovation investment in Shaanxi[4]. From 2017 to 2020, the gravity center fell back southwestward, which was directly related to the elevation of the Chengdu–Chongqing Twin-City Economic Circle as a national strategy[5]. From 2020 to 2023, the gravity center tended to be stable with a sharp reduction in moving distance, marking that the innovation ecological spatial pattern in western China entered a stage of steady optimization from rapid adjustment. Combined with multi-dimensional hierarchical gravity center comparison, the gravity center of innovation output is generally eastern, while the gravity center of innovation input tends to be northwest. Spatial trajectories of different dimensions are significantly different, which confirms the conclusion of hierarchical ellipse analysis[1].

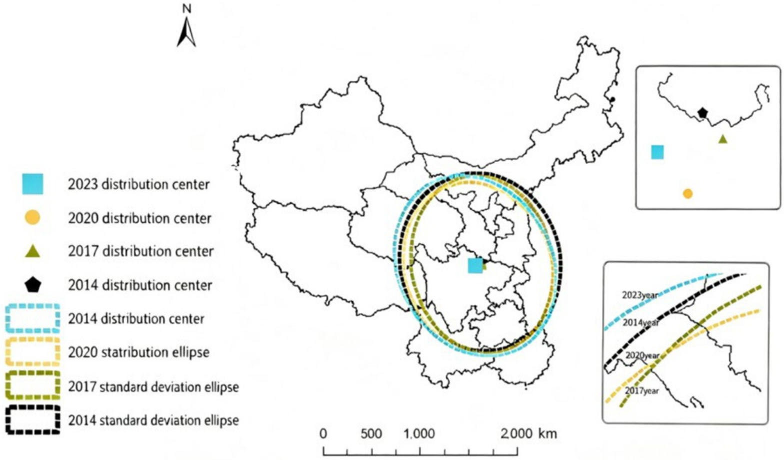

Fig. 1. Hierarchically Weighted Standard Deviational Ellipses of the Comprehensive Innovation Ecosystem Index in Western China (2014–2023).

4 Evolution of Spatial Correlation Structure of Innovation Ecosystem in Western China

4.1 Global Spatial Autocorrelation Analysis

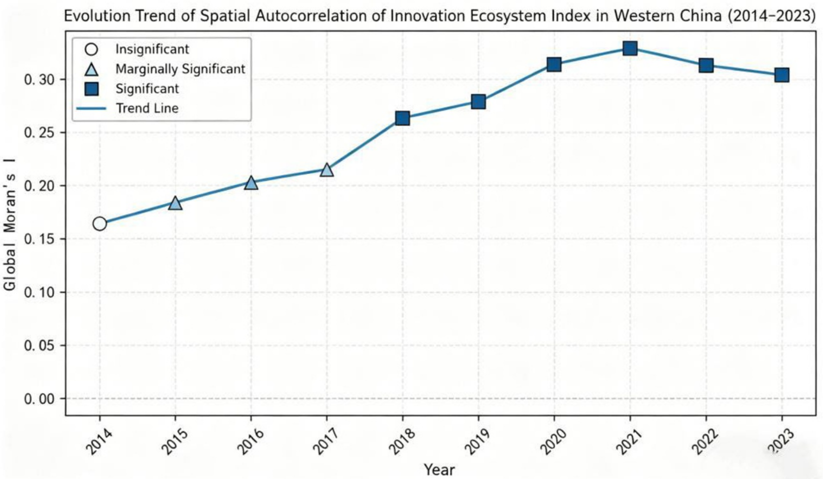

Fig. 2. Evolution Trend of Global Moran's I of Innovation Ecosystem Index in Western China (2014–2023)

Based on the constructed spatial weight matrix, this study conducts a global spatial autocorrelation analysis on the innovation ecosystem index in western China from 2014 to 2023, and calculates the Global Moran's I index for each year (Figure 2). The results show that except for 2014, the Moran's I values of other years are positive and all pass the significance test of at least 10% level, among which 2018–2023 all pass the 5% level test, proving that there is a significant positive spatial correlation in the innovation ecosystem in western China, namely spatial agglomeration. From the temporal evolution, the index rises from 0.164 in 2014 to a peak of 0.329 in 2021 and then slightly falls back, with the agglomeration effect first enhanced then stabilized[7].

4.2 Local Spatial Agglomeration and Hotspot–Coldspot Evolution

To further identify the specific types of local spatial agglomeration, this paper conducts LISA analysis and selects LISA cluster maps of four representative years: 2014, 2015, 2018 and 2023. As shown in Figure 3, the spatial pattern of innovation ecology in western China has gone through three-stage evolution: from 2014 to 2017, it changed from Chongqing's single core to Chongqing–Shaanxi dual core[2]; from 2018 to 2020, the pattern was reconstructed, forming a Chongqing–Guizhou innovation corridor; from 2021 to 2023, the pattern was stabilized and solidified. Stability tests show 100% retention for Chongqing (hotspot) and Xinjiang (coldspot), 60% for Guizhou, and 30% for Shaanxi, indicating spatial structural transformation.

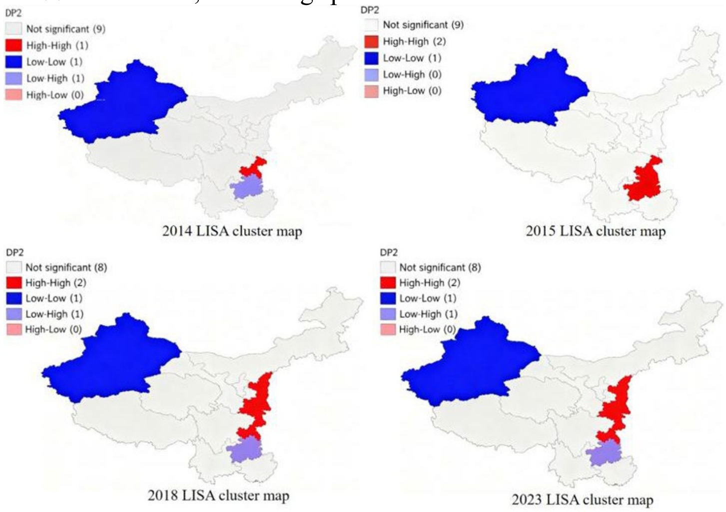

Fig. 3. LISA Cluster Maps in Representative Years

4.3 Spatial Heterogeneity and Convergence Characteristics

To systematically evaluate the spatial difference degree of the innovation ecosystem index in western China, this paper calculates the coefficient of variation (CV) from 2014 to 2023. The CV results show that (Figure 4), from 2014 to 2016, it rose from 0.69 to 0.75, indicating expanded regional differences; from 2016 to 2023, it continued to drop to 0.49, with significant convergence of differences, indicating that the innovation diffusion effect gradually appears and the balanced development of the region continues to improve[3].

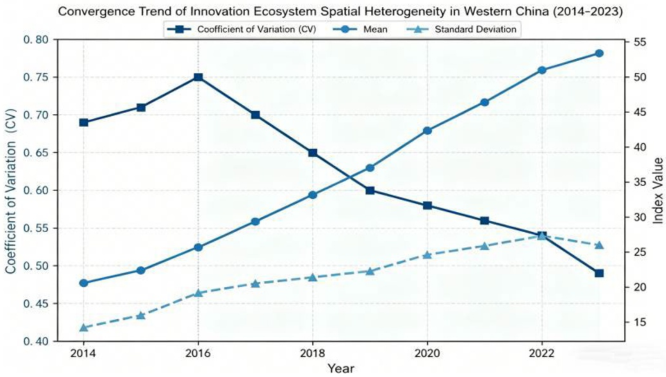

Fig. 4. Temporal Change of Spatial Heterogeneity of Innovation Ecological Index (2014–2023).

5 Temporal Evolution and Difference Decomposition of Innovation Ecosystems in Western China

5.1 Temporal Evolution Characteristics of Innovation Ecological Index

Based on the innovation ecosystem index (DP2) of 12 provinces in western China from 2014 to 2023, the development of innovation ecosystem shows a significant continuous growth trend. As shown in Figure 5, the average value of the innovation ecosystem index in western China rose from 20.58 in 2014 to 53.41 in 2023, with a cumulative growth of 159.4% and an average annual growth rate of 11.2%, which can be divided into three stages: exploratory development period (2014–2016) with a growth rate of 11.7%; accelerated development period (2017–2020) with a growth rate of 13.0%; high-quality transformation period (2021–2023) with a growth rate of 7.2%, shifting from scale expansion to quality improvement.

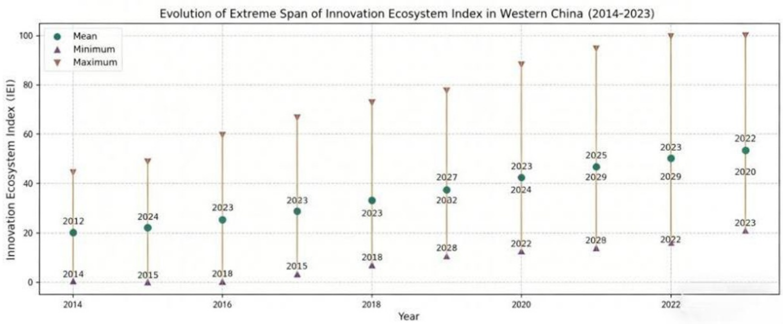

Fig. 5. Evolution of Extreme Range of Innovation Ecosystem Index in Western China (2014–2023)

5.2 Nested Theil Coefficient Difference Decomposition

This paper first classifies 12 provinces into three types of regions (high innovation, medium innovation, and low innovation) by K-Means clustering, and then conducts nested Theil coefficient decomposition to replace the traditional southwest–northwest geographical division, making the difference sources more consistent with the reality of innovation development. The results are shown in Table 2: the total Theil coefficient still shows a trend of "first expansion then convergence", reaching a peak of 0.3003 in 2016 and falling to 0.1159 in 2023. Regardless of the partition method used, intra-regional differences account for more than 76% for a long time, constituting the main source of overall differences; inter-regional differences account for less than 25%, indicating that the innovation ecological gap in western China does not originate from geographical plate division, but from unbalanced development within provinces and inter-provincial gradient differences. 2016 became a key turning point for differences from expansion to convergence, which is highly consistent with the implementation of regional collaborative innovation policies[5].

Table 2. Nested Theil Coefficient Decomposition Results Optimized by K-Means Clustering in Western China (2014–2023)

Year	Total Theil Coefficient	Inter-regional Difference	Intra-regional Difference	Inter-regional Proportion (%)	Intra-regional Proportion (%)
2014	0.2397	0.0202	0.2194	8.43	91.53
2016	0.3003	0.0172	0.2832	5.73	94.31
2020	0.1637	0.0349	0.1288	21.32	78.68
2023	0.1159	0.0203	0.0955	17.52	82.40

6 Stage Characteristics of Gravity Center Movement and Robustness Test

6.1 Three-stage Characteristics of Gravity Center Movement

To objectively divide the stages of gravity center movement, the Bai–Perron structural break test is conducted on the gravity center movement distance series from 2014 to 2023. The results show that there are two significant breakpoints at the 5% significance level: 2016 ($F=11.28$, $p=0.009$) and 2020 ($F=8.94$, $p=0.026$) As shown in Figure 6, in the exploratory development period (2014–2016), the movement distance fluctuates greatly and the direction is scattered, showing obvious characteristics of policy trial and error. In the accelerated development period (2017–2020), the movement distance decreases and the direction is concentrated, with enhanced path dependence. In the high-quality transformation period (2021–2023), the movement distance rises and adjusts to the northwest, which is in line with the national westward opening strategy. The 95% confidence intervals verify the robustness of stage division.

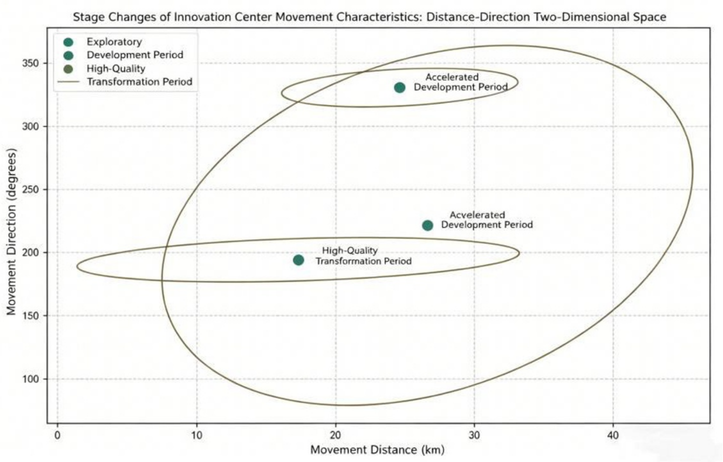

Fig. 6. Bivariate Phase Ellipse of Gravity Center Movement: Distance–Direction Two-Dimensional Space

6.2 Robustness Test

Four M-estimators, Huber, Tukey, Hampel, and Andrews, are adopted for the robustness test. The estimated values of movement distance and direction are highly consistent, with a maximum difference of less than 3 km, confirming that the evolutionary laws in this paper are true and robust and not disturbed by outliers, as shown in Table 3.

Table 3. Robustness Test Table.

	Time Period	Huber M-estimator	Tukey Biweight	Hampel M-estimator	Andrews Wave
Moving Distance	2014–2016	26.62	26.94	26.62	26.94
	2017–2020	12.46	9.61	12.40	9.61
	2021–2023	24.62	24.62	24.62	24.62
Moving Direction	2014–2016	221.41	222.81	221.41	222.82
	2017–2020	192.40	192.93	193.85	192.93
	2021–2023	330.49	330.49	330.49	330.49

Note: a. Weighting constant = 1.339; b. Weighting constant = 4.685; c. Weighting constants = 1.700, 3.400, 8.500; d. Weighting constant = 1.340π.

7 Conclusions and Optimization Suggestions

7.1 Main Conclusions

Taking 12 provinces in western China as research objects, this paper constructs an innovation ecosystem index via the DP2 method using 2014–2023 panel data, and identifies its spatiotemporal evolution using spatial statistical methods. Results show that the innovation ecosystem in western China presents a significant core–periphery structure. Hierarchical ellipse tests confirm obvious spatial clustering differences across innovation dimensions. Innovation resources are concentrated in Sichuan, Shaanxi, and Chongqing, while peripheral provinces remain weak. The gravity center moves northwest, southwest, and then stabilizes. Global spatial autocorrelation is significantly positive, with hotspots shifting from Chongqing–Shaanxi to Chongqing–Guizhou and Xinjiang as a persistent cold spot. Regional differences first expand then converge. Supported by the Bai–Perron test, the evolution has three stages with growth shifting from scale expansion to quality improvement. Disparities mainly stem from inter-provincial gaps rather than geographic divisions. K-Means clustering-based decomposition and multiple M-estimator robustness tests all verify the reliability of the conclusions.

7.2 Optimization Suggestions

First, strengthen core innovation poles and consolidate the Sichuan–Shaanxi–Chongqing highland, and spill innovation resources to marginal areas. Second, improve cross-regional collaboration mechanisms, break inter-provincial innovation barriers, strengthen the construction of southwest innovation corridor and northwest linkage belt, and eliminate the innovation island effect. Third, focus on balanced intra-regional development, increase investment in science and technology, education, and talents in backward provinces and cities, and make up for shortcomings of grassroots innovation. Fourth, implement differentiated and precise policies: focus on original innovation and achievement transformation in core regions, strengthen subject collaboration in medium-level provinces, and prioritize consolidating the innovation foundation environment in weak areas, so as to comprehensively promote the high-quality, collaborative and sustainable development of innovation ecosystems in western China.

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