Postprint: Spatiotemporal Differentiation Patterns of Economic Resilience in the Yellow River Basin Based on Multi-dimensional Evaluation Methods

Authors: Xue Chenhao, Bai Yongping, Wang Shengpeng

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Abstract

Scientific measurement of economic resilience in the Yellow River region constitutes a crucial step toward enhancing regional economic resilience and achieving high-quality development. This study constructs an indicator system to measure the economic resilience level of the Yellow River region from 2003 to 2022 across three dimensions: resistance, recovery, and transformation, and employs the Theil index and Moran' s I to analyze the disparities and spatial correlation of economic resilience in the region. The results indicate that: (1) During the study period, the economic operation of the Yellow River region remained generally stable, demonstrating robust economic resilience, yet a considerable gap persists compared with the national economic resilience level. Among the subsystems, the recovery dimension achieved the highest score, while transformation scored the lowest. (2) High-resilience areas are predominantly distributed across the Shandong Peninsula, provincial capitals in central and western regions, and cities abundant in mineral resources, whereas low-resilience areas are primarily located in Qinghai, Ningxia, Gansu, Shaanxi, most parts of Henan, western Inner Mongolia, and western Shandong. Economic resilience at the prefecture-level scale exhibits a pronounced center-periphery structure. (3) Throughout the study period, the overall disparity in economic resilience levels across the Yellow River region demonstrated a narrowing trend in most years, with the contribution rate of intra-regional differences exceeding 75%, underscoring the need to address intra-regional coordinated development. (4) During the study period, Moran' s I for economic resilience in the Yellow River region remained positive, indicating overall positive spatial correlation. The local spatial clustering distribution is dominated by low-low clusters and high-high clusters, with the former concentrated primarily in Qinghai, Gansu, and Ningxia, and the latter mainly distributed in Shandong.

Full Text

Preamble

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Spatio-temporal Differentiation Patterns of Economic Resilience in the Yellow River Region Based on Multi-dimensional Evaluation Methods

XUE Chenhao[1,2], **BAI Yongping**[1], **WANG Shengpeng**[2]
[1] College of Geography and Environmental Science, Northwest Normal University, Lanzhou, Gansu, China
[2] College of Management, Northwest Minzu University, Lanzhou, Gansu, China

Abstract: Scientifically measuring economic resilience in the Yellow River region represents a critical step toward enhancing regional economic resilience and achieving high-quality development. This study constructed an indicator system to measure economic resilience levels in the Yellow River region from 2003 to 2022 across three dimensions: resistance, recovery, and transformation. The Theil index and Moran' s index were introduced to analyze regional disparities and spatial correlations in economic resilience. Results indicate: (1) During the study period, the Yellow River region maintained stable economic operation with strong overall resilience, though a significant gap remains compared to national economic resilience levels. Among subsystems, the recovery dimension scored highest while transformation scored lowest. (2) Higher resilience areas are primarily distributed in the Shandong Peninsula, provincial capitals in central and western regions, and mineral-rich cities. Lower resilience areas are mainly concentrated in Qinghai, Ningxia, most of Gansu, Shaanxi, Henan, western Inner Mongolia, and western Shandong, exhibiting a clear center-periphery structure at the prefecture level. (3) The overall disparity in economic resilience across the Yellow River region showed a narrowing trend during most years of the study period, with intra-regional differences contributing more than 75% to total inequality, highlighting the need for coordinated regional development. (4) Moran' s index values for economic resilience remained positive throughout the study period, indicating overall positive spatial correlation. Local spatial clustering was dominated by low-low agglomerations (concentrated in Qinghai, Gansu, and Ningxia) and high-high agglomerations (primarily in the Shandong Peninsula), with few and scattered high-low and low-high clusters.

Keywords: economic resilience; spatiotemporal differentiation; indicator system; Yellow River region

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Introduction

A profound understanding of China' s economic resilience and potential, coupled with scientific evaluation of regional economic resilience patterns, forms the foundation for regional economic systems to withstand external shocks and achieve sustained, stable development. The unique natural and economic characteristics of the Yellow River region make it highly susceptible to external disruptions that can interrupt development trajectories and trigger decline. As complexity and uncertainty in regional economic development increase, the region must both respond to external shocks and enhance economic resilience while improving coordinated development to achieve high-quality growth. Therefore, studying the spatiotemporal differentiation patterns of economic resilience in the Yellow River region holds significant practical importance for enhancing the region' s capacity to respond to external shocks and formulate effective economic development strategies.

Recent years have witnessed the extension of resilience research into ecology, anthropology, geography, and economics, yielding concepts such as ecological resilience, evolutionary resilience, social resilience, urban resilience, and economic resilience. Current domestic research on regional economic resilience primarily explores three aspects: First, scholars examine connections between regional economic resilience and various factors from different perspectives, including analyses from strategic coupling evolution viewpoints and investigations into the mechanisms linking digital economy and tourism economy with regional economic resilience. Second, research addresses measurement methods and spatiotemporal patterns of regional economic resilience, providing important theoretical foundations and technical support for this study. Third, studies analyze influencing factors of regional economic resilience, identifying industry as a key driver while also highlighting the significant impacts of government regulation.

Measurement methods for regional economic resilience can be summarized as case analysis, indicator systems, key variables, and function analysis. Case analysis describes regional economic recovery and development paths following shocks. The indicator system approach offers convenience and flexibility with strong data availability and rich, representative indicators that comprehensively reflect regional economic systems' ability to resist risks and expand development paths, making it widely adopted in recent research. Key variable methods typically employ employment or GDP growth rates but neglect dynamic characteristics and marginal contributions of other economic variables. Function analysis, such as time-varying parameter factor-augmented vector autoregression models, has also been applied to measure macroeconomic resilience.

In the context of the Yellow River region, previous studies have measured industrial resilience through resistance and recovery dimensions, noting that industrially diversified regions recover more easily from external shocks. Other research has used GDP growth rates to measure economic resilience, revealing spatial characteristics and influencing factors. However, these approaches overlook the fact that regional economic resilience results from multiple factors and faces both identifiable external shocks and "slow-burn" disturbances without clear temporal boundaries. This study argues that the indicator system method better aligns with research objectives and content for measuring economic resilience in the Yellow River region.

1 Data and Methods

1.1 Study Area

This study examines eight provincial-level regions along the Yellow River: Qinghai, Gansu, Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region, Shanxi, Shaanxi, Henan, and Shandong (hereinafter referred to as Qinghai, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong), encompassing 73 prefecture-level administrative units. Following principles of spatial proximity and regional integrity, the study area is divided into three sub-regions for basin-scale analysis: upstream (Qinghai, Gansu, Ningxia, Inner Mongolia), midstream (Shanxi, Shaanxi, Sanmenxia, Luoyang, Jiaozuo, and Jiyuan in Henan), and downstream (Shandong and other Henan prefectures).

1.2 Data Sources and Processing

Data primarily derive from the *China Statistical Yearbook*, *China Labor Statistical Yearbook*, *China High-tech Industry Statistical Yearbook*, *China City Statistical Yearbook*, CSMAR database, and provincial statistical yearbooks and national economic and social development bulletins for the 2003-2022 period. To ensure consistent accounting standards, data for Laiwu City were merged into Jinan City, while Jiyuan City was treated as a prefecture-level unit. Missing data were interpolated using adjacent years. Spatial data were obtained from the Ministry of Natural Resources Standard Map Service.

1.3 Indicator System Construction

Evolutionary economic geography suggests that measuring regional economic resilience requires assessing systems' capacity to correct development trajectory deviations and create new development paths amid external disturbances and internal gradual changes. This necessitates comprehensive reflection through multiple evaluation dimensions and indicators. Scholars typically divide dimensions according to economic subsystems' functions (financial, monetary, innovation) or conceptual components (resistance-recovery, reconstruction-renewal). This study constructs an indicator system across three dimensions—resistance, recovery, and transformation—to comprehensively measure economic resilience levels in the Yellow River region . The entropy method was employed to calculate comprehensive scores.

1.4 Analytical Methods

1.4.1 Theil Index The Theil index was used to calculate disparities in economic resilience across the Yellow River region, measuring overall differences, intra-regional and inter-regional variations, and their respective contributions. The formulas are as follows:

$$T = \sum_{q=1}^{k} \frac{S_q}{S} \times \ln\left(\frac{S_q}{\bar{S}}\right)$$

$$T_p = \sum_{q=1}^{k_p} \frac{S_{pq}}{S_p} \times \ln\left(\frac{S_{pq}}{\bar{S}_p}\right)$$

$$T_b = \sum_{p} \frac{S_p}{S} \times \ln\left(\frac{S_p}{\bar{S}}\right)$$

Where T represents the overall Theil index (range [0,1], with smaller values indicating less disparity), q indexes prefectures, k is the total number of prefectures, S_q is the economic resilience level of prefecture q, $\bar{S}$ is the average resilience level, T_p measures regional disparity, k_p is the number of prefectures in region p, S_{pq} is resilience of prefecture q in region p, and $\bar{S}_p$ is the mean resilience of region p. The overall index decomposes into intra-regional (T_w) and inter-regional (T_b) components, with contribution rates defined as T_w/T and T_b/T respectively.

1.4.2 Exploratory Spatial Data Analysis ArcGIS was used to characterize spatial distribution patterns. Spatial autocorrelation analysis, including global and local autocorrelation, was applied. Global Moran' s I measures overall spatial association:

$$I = \frac{N}{S_0} \times \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} \omega_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\sum_{i=1}^{N}(X_i - \bar{X})^2}$$

Where N is the total number of prefectures, X_i is the economic resilience index, $\bar{X}$ is the mean, S_0 is the aggregate of spatial weights, and ω_{ij} is the spatial weight matrix (1 for adjacent, 0 otherwise). Statistical significance was tested using $z(I) = \frac{I - E(I)}{\sqrt{Var(I)}}$.

Local Moran' s I reveals local spatial relationships:

$$I_i = Z_i \sum_{j=1}^{N} \omega_{ij} Z_j$$

Where Z_i and Z_j are standardized values.

2 Results

2.1 Temporal Evolution of Economic Resilience

2.1.1 Overall Trends During 2003-2022, economic resilience in the Yellow River region followed a "stable growth-recovery growth" trajectory [Figure 1: see original paper]. The resilience index grew fastest during 2003-2007, increasing from 0.201 to 0.274 (6.35% annual growth). Negative growth occurred only in 2020 (-1.42%), followed by rapid recovery to 0.317 in 2022. The region demonstrated stable operation with strong resilience, though consistently lagging national levels. During COVID-19, the region' s resilience indices were 90.15% (2020) and 93.23% (2021) of national levels, higher than the 88.63% in 2009 during the financial crisis. In normal years, the region' s resilience fluctuated between 76.65% and 87.53% of national levels.

2.1.2 Subsystem Analysis Across the three dimensions, recovery scored highest, followed by resistance, with transformation scoring lowest [Figure 2: see original paper], indicating that recovery drives resilience improvement while transformation remains the weakest link. Resistance showed clear fluctuating growth, particularly rapid during 2016-2022. Recovery, despite highest scores, exhibited slowing growth. Transformation growth fell between the other two dimensions. This suggests that resistance-related indicators (economic development level, industrial chain status) may improve in the short term, while recovery and transformation indicators require longer timeframes. Although overall resilience improved, volatility within subsystems indicates that a robust, stable, mutually supportive system has not yet formed, with regional imbalances potentially widening gaps with developed regions.

2.2 Spatial Patterns of Economic Resilience

2.2.1 Overall Spatial Distribution Provincial-level results show all eight provinces experienced fluctuating growth, but disparities widened [Figure 3: see original paper]. Shandong maintained the highest resilience, increasing from 0.395 to 0.535, significantly exceeding other provinces. Shaanxi ranked second, rising from 0.223 to 0.354, peaking in 2021. Qinghai showed the slowest growth (0.155 to 0.208). At the prefecture level, a clear center-periphery structure emerged [Figure 4: see original paper]. Using natural breaks, resilience was classified into four levels. High and higher resilience areas concentrated in Shandong's provincial capital and Jiaodong economic circles, provincial capitals in central-western provinces, and mineral-rich cities. Low and lower resilience areas dominated southwestern/northwestern Shandong, Alxa League, Xilingol League, Ordos, most of Henan (except Zhengzhou and Jiyuan), most of Shaanxi (except Xi' an and Yulin), most of Gansu (except Lanzhou and Jinchang), and all of Qinghai and Ningxia.

The 2008 financial crisis significantly impacted Shandong and Henan. In 2009, low-resilience areas expanded to include all of Qinghai and Ningxia, most of

Gansu, Inner Mongolia, Shaanxi, Shanxi, and parts of Henan and Shandong —these regions showed poor resistance and underdeveloped tertiary industries. High-resilience cities included Jinan, Zibo, Dongying, Qingdao, Yantai, Weihai, Jiyuan, and Jiayuguan. Higher-resilience areas comprised Tai' an, Binzhou, Weifang, Rizhao, Taiyuan, Zhengzhou, Jiaozuo, Luoyang, Xi' an, Yulin, Yan' an, and Lanzhou. Resource-based cities' resilience declined due to international mineral price fluctuations.

Post-crisis, Shandong' s pattern remained stable while other provinces showed high resilience in provincial capitals and resource cities. Under industrial restructuring policies, cities with single-industry structures exhibited lower adjustment capacity and resilience. By 2022, Shandong' s pattern persisted, while other provinces maintained high resilience in Zhengzhou, Jiyuan, Xi' an, Yulin, Taiyuan, and Lanzhou. Notably, Gansu' s resilience declined significantly.

2.2.2 Basin-Scale Variation Theil index decomposition reveals overall disparity trends . The index fluctuated upward then slowly rose from 0.201 to 0.274, with the overall gap narrowing in most years, demonstrating the effectiveness of national policies (fiscal 倾斜, Western Development, regional coordination, poverty alleviation). However, a notable "upturn" in 2022 warrants attention.

Intra-regional differences contributed over 75% to total inequality (averaging 78.66%), while inter-regional contributions averaged 21.34%, indicating that intra-regional coordination should be prioritized. Further decomposition shows upstream disparity was largest and most volatile (0.303 to 0.234), midstream most stable (0.111 to 0.093), and downstream slowly declining (0.156 to 0.112). Upstream differences stem from uneven development between resource-based cities and provincial capitals versus peripheral agricultural areas. Downstream disparities reflect gaps between high-performing Shandong cities and Henan cities.

2.2.3 Spatial Correlation Global Moran' s I remained positive throughout 2003-2022, passing significance tests and showing "continuous upward-rapid upward" trends , indicating significant positive spatial autocorrelation. Local spatial autocorrelation analysis [Figure 5: see original paper] revealed distinct clustering patterns:

- **High-high clusters**: Concentrated in the Shandong Peninsula (excluding certain peripheral cities in different years), representing adjacent high-resilience areas.
- **Low-low clusters**: Extensively distributed across Qinghai, Gansu, and Ningxia (e.g., Hainan, Golog, Huangnan, Gannan, Linxia, Longnan, Guyuan), showing homogeneous low resilience.
- **High-low clusters**: Isolated high-resilience cities surrounded by low-resilience areas (Lanzhou, Baoji, Jinchang in various years).
- **Low-high clusters**: Low-resilience cities surrounded by high-resilience areas (Liaocheng, Linyi, Zaozhuang in Shandong).

3 Discussion

Current research on regional economic resilience has extensively covered theoretical and empirical aspects, focusing on spatiotemporal evolution, regional disparities, and influencing mechanisms. However, few studies examine intraregional spatiotemporal differences. This study makes several contributions: First, it selects a typical region combining basin and administrative boundaries, explaining how economic resilience evolves spatiotemporally and how internal differences affect it. Second, it verifies that loose economic linkages, internal disparities, developmental stage characteristics, and lagging industrial upgrading constrain high-quality development in the Yellow River Basin, consistent with existing theoretical perspectives. Third, it employs a comprehensive indicator system with Theil and Moran indices to analyze disparities and spatial correlations, empirically testing resilience theory while revealing internal differentiation mechanisms.

Policy recommendations include: (1) Accelerating new quality productive forces development and modern industrial systems by coordinating traditional industry transformation with emerging industry cultivation, promoting intelligent, green, and high-end development. (2) Strengthening cross-regional cooperation mechanisms based on ecological systems, resource endowments, and modern industrial division of labor to break administrative barriers and exploit comparative advantages. (3) Exploring resilience enhancement paths by establishing high-quality development policy systems, improving talent recruitment and incentive mechanisms, and increasing innovation support.

Limitations include: Resilience evolution research remains nascent without unified measurement paradigms. This study did not explicitly identify resilience stages or conduct dynamic forecasting, nor did it objectively analyze influencing factors or differentiate responses to sudden shocks versus slow disturbances. Future research should address these gaps for more comprehensive understanding.

4 Conclusions

Although economic resilience in the Yellow River region improved steadily during 2003-2022, significant gaps persist with national levels, and development capacity differences among provinces and prefectures will likely continue. In the new development stage, long-standing issues of ecological fragility, loose economic linkages, and inadequate development will affect China' s overall economic resilience and vitality. Key conclusions include:

1. Economic resilience followed a "stable growth-recovery growth" pattern, with the index reaching its peak in 2022. The region demonstrated stable operation and strong resilience, though remaining substantially below national levels. Recovery scored highest among subsystems, transformation lowest.

2. Provincial resilience indices all fluctuated upward, but disparities widened,

with Shandong significantly outperforming others. At the prefecture level, a clear center-periphery structure emerged, with high resilience in the Shandong Peninsula, provincial capitals, and mineral-rich cities, while low resilience dominated extensive areas in western provinces.

3. Overall spatial disparity showed "fluctuating upward-slowly upward" trends, narrowing in most years due to national regional coordination strategies. Intra-regional differences contributed over 75% to total inequality, highlighting the need for coordinated development.
4. Positive Moran' s index values indicated significant positive spatial correlation throughout the study period. Local clustering was dominated by low-low agglomerations (Qinghai, Gansu, Ningxia) and high-high agglomerations (Shandong Peninsula), with few high-low and low-high clusters.

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