Postprint: Multidimensional Perspective on County-Level Shrinkage Identification and Influencing Factor Analysis in the Agro-Pastoral Ecotone of Northern China

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Abstract

Based on three dimensions of population, economy, and space, this study identifies county-level shrinkage types in the farming-pastoral ecotone of northern China from 2000 to 2020 using a shrinkage degree model and multi-index comprehensive evaluation method, and simultaneously employs a Multiscale Geographically Weighted Regression (MGWR) model to explore the influencing factors of county-level shrinkage from a spatial differentiation perspective. The results indicate that: (1) In terms of shrinkage quantity and severity, population shrinkage is the most severe, with a growth rate reaching 64.15% and the widest coverage; followed by spatial shrinkage and economic shrinkage, with growth rates of 30.19% and 7.55%, respectively. (2) From the perspective of spatiotemporal evolution characteristics, counties experiencing comprehensive shrinkage and single-dimensional shrinkage in population, economy, and space are mainly concentrated in the Northeast and Inner Mongolia regions, exhibiting a shrinkage trend of "encircling from the periphery to the center." (3) From the perspective of combination relationships among different dimensions, county-level shrinkage types are gradually becoming more multidimensional. During 2000–2010, the farming-pastoral ecotone of northern China only exhibited single-dimensional population shrinkage; whereas during 2010–2020, shrinkage types became more diversified, encompassing two-dimensional and three-dimensional shrinkage, with population-space shrinkage being the primary type. (4) From the perspective of driving factors, county-level shrinkage in the farming-pastoral ecotone of northern China is mainly influenced by local fiscal expenditure, educational resources, and fixed-asset investment, with significant spatial differences among these driving factors. Therefore, implementing zoned management is crucial for achieving sustainable county-level development. The research find-

ings further enrich the research perspectives on urban shrinkage and provide scientific reference and theoretical support for enhancing county-level vitality in the farming-pastoral ecotone of northern China and achieving high-quality urban development.

Full Text

Preamble

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Multidimensional Identification of County Shrinkage and Analysis of Influencing Factors in the Agro-Pastoral Zone of Northern China

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Abstract: Based on three dimensions—population, economy, and space—this study identifies types of county shrinkage in the agro-pastoral zone of northern China from 2000 to 2020 using a shrinkage degree model and multi-index comprehensive evaluation method. It further explores the driving factors of county shrinkage from a spatial differentiation perspective employing a multiscale geographically weighted regression (MGWR) model. The results reveal: (1) Population shrinkage is the most severe, with a growth rate of 64.15% and the widest geographic coverage, followed by spatial shrinkage and economic shrinkage with growth rates of 30.19% and 7.55%, respectively. (2) In terms of spatiotemporal evolution, comprehensive shrinkage and single-dimensional shrinkage in population, economy, and space are primarily concentrated in Northeast China and Inner Mongolia, demonstrating a trend of "encircling from the edge to the center." (3) Regarding the interplay of different dimensions, county shrinkage types are gradually becoming multidimensional. From 2000 to 2010, only unidimensional population shrinkage was observed in the agro-pastoral zone of northern China, whereas from 2010 to 2020, shrinkage types diversified, encompassing both two- and three-dimensional shrinkage, predominantly characterized by population-space shrinkage. (4) According to MGWR model analysis, county shrinkage in this region is mainly influenced by local fiscal expenditures, educational resources, and fixed asset investments, with significant spatial variation among these driving factors. Therefore, implementing zonal management is crucial for achieving sustainable county development. This study enriches research perspectives on urban shrinkage and provides scientific references and theoretical support for enhancing county vitality in the agro-pastoral zone of northern China, ultimately contributing to high-quality urban development.

Keywords: urban shrinkage; multidimensional perspectives; ecological security; agro-pastoral zone; northern China

1 Introduction

Urban shrinkage is an inevitable phenomenon in the urbanization process, yet it has given rise to a series of problems including economic depression, land abandonment, and escalating local debt risks, making it a core issue that urgently needs to be addressed for global cities to achieve high-quality, sustainable development. Currently, scholars typically regard population decline as the primary indicator for identifying shrinking cities, focusing on phenomenon description and conceptual definition, specific measurement and identification, spatiotemporal evolution, influencing factors, and exploring existing problems and countermeasures from multiple perspectives. Meanwhile, many scholars have also conducted international comparisons to study differences and governance experiences between Chinese and Western shrinking cities. In recent years, urban shrinkage in China has become increasingly prominent with complex and diverse types. Objectively and accurately identifying urban shrinkage phenomena, exploring their influencing factors, and scientifically addressing the challenges posed by urban shrinkage have become important tasks for the second half of China's new urbanization.

The concept of "urban shrinkage" was first proposed by Häußermann and Siebel in 1988 to describe the hollowing-out of cities caused by population loss and has been widely accepted and applied. Currently, scholars typically use population decline as the main indicator to identify shrinking cities, focusing on phenomenon description and conceptual definition, specific measurement and identification, spatiotemporal evolution, and influencing factors, while also exploring existing problems and countermeasures from multiple perspectives. Many scholars have conducted international comparisons to study differences and governance experiences between Chinese and Western shrinking cities. With deepening research, scholars have gradually shifted from single-dimensional to multidimensional perspectives to enrich the concept of urban shrinkage, reflecting multiple dimensions including population, economy, and society. From a two-dimensional perspective, many scholars have used population and economic characteristics to conduct identification studies on China as a whole and specific regions such as old industrial bases and the Yellow River Basin. From a multidimensional perspective, researchers have used population and economy as core dimensions, adding land use, space, and other perspectives for combined analysis, constructing comprehensive indicators using multi-source data such as resource environment and facility services, science and technology, culture, education, and labor force.

China has conducted extensive research on the spatiotemporal distribution and characteristics of urban shrinkage, primarily focusing on Northeast China and urban agglomerations. Over 70% of shrinking cities in Northeast China exhibit a contradictory development pattern of continuous construction land expansion. The Pearl River Delta region has identified 17 shrinking cities, of which 12 continued the population negative growth trend. Urban shrinkage in the Pearl River Delta region is classified into potential shrinkage and significant shrinkage. Influencing factors of urban shrinkage in China mainly include economic development factors, population structure, social institutions, and location environment. Different cities have varying development stages and geographical environments, and these factors evolve over time with different modes and intensities of action.

In summary, although many scholars have studied urban shrinkage in most regions of China, they have mainly focused on economically developed or typical cities, paying less attention to urban shrinkage phenomena and mechanisms in some underdeveloped areas. The agro-pastoral zone of northern China has sparse population distribution due to historical reasons, with relatively sparse urban distribution. In recent years, with the intensification of globalization and urbanization, many cities in this zone have shown obvious shrinkage trends, which to some extent have become constraints on regional coordination and high-quality development of urban-rural integration. Currently, research on the causes and mechanisms of shrinkage in this zone mainly focuses on partial cities in Inner Mongolia and the Yellow River Basin, lacking holistic research and analysis. Based on this, this paper comprehensively analyzes the spatiotemporal differentiation characteristics and influence mechanisms of county shrinkage in the agro-pastoral zone of northern China from 2000 to 2020 from multiple dimensions including population, economy, and space, aiming to provide scientific references and data support for enhancing county vitality, promoting smart shrinkage, and achieving high-quality development in this region.

1.1 Study Area Overview

The agro-pastoral zone refers to the transitional zone between agricultural and pastoral areas, where two different production and management methods spatially intersect and gradually substitute each other temporally. Moreover, this zone is also a vulnerable ecosystem transition zone that is particularly sensitive to global change. The agro-pastoral zone of northern China includes 106 counties (districts) across seven provinces (autonomous regions) of Heilongjiang, Liaoning, Jilin, Inner Mongolia, Gansu, Ningxia, Shanxi, Hebei, and Shaanxi, with a total area of approximately 65.46$\times 10^{4}$ km^2. The resident population decreased from 3.31×10^{7} in 2000 to 2.81×10^{7} in 2020, a reduction of 3.14×10^{6} people. In terms of economy, the GDP increased from 2.81×10^{4} yuan in 2000 to 1.64×10^{8} yuan in 2020. The region has a typical temperate semi-arid continental monsoon climate, with an average annual temperature of 2–8°C and average annual rainfall of 250–500 mm.

Note: Based on the standard map with approval number GS(2020)4619 from the Ministry of Natural Resources Standard Map Service website, with no modifications to the base map boundaries. The same applies below.

[Figure 1: see original paper] Schematic diagram of the study area

1.2 Construction of Multidimensional Indicator System

When different regions exchange materials, energy, and information, they promote the transformation of regional internal population structure, economic structure, and spatial structure toward heterogeneity and differentiation. Traditional urban economics theory holds that "urban development is a process of flow and agglomeration of production factors such as capital and labor in urban space, and urbanization is the spatial expression of urban growth." Based on this, urban shrinkage can be understood as the reduction in density and scale of population and economic elements, accompanied by vacancy and inefficient utilization of structures and public infrastructure in space. Therefore, this paper studies the spatiotemporal differentiation characteristics and evolution processes of county transition from growth or enhancement trends to development stagnation or even decline in the agro-pastoral zone of northern China from three aspects: population change, economic development, and spatial utilization.

In terms of the population dimension, we selected population scale and population development aspects, including permanent population, birth rate, and total employed population (Table 1). Population loss is an important manifestation of urban shrinkage. Permanent population is an important indicator to measure the size of a region's population. Birth rate is an important factor to measure population growth trends. The reduction of employed population indicates the outflow of development factors and increases the possibility of urban shrinkage. In terms of the economic dimension, we selected economic level and economic structure aspects to measure the degree of economic shrinkage. The economic level includes GDP per capita and fiscal revenue, which reflect the degree of economic agglomeration and economic vitality. Economic structure includes the proportion of primary, secondary, and tertiary industries. The higher the proportion of secondary and tertiary industries, the higher the degree of economic structure optimization. In terms of the spatial dimension, we selected average nighttime light index, ghost city index, and ecological land to measure the density and sustainability of human activity development factors. Among them, the ghost city index is the ratio of non-agricultural population to built-up area in a county. The denser the urban development factors, the higher the average nighttime light brightness, the smaller the ghost city index, and the lower the risk of urban shrinkage.

Comprehensive evaluation indicator system and weighting coefficients

1.3 Data Sources

The study period is 2000–2020. Population data were obtained from the fifth, sixth, and seventh national population censuses. Economic data were sourced from the corresponding years of the *China County Statistical Yearbook* and national economic statistical bulletins of each county. Land use data were derived from 30 m resolution multi-temporal land use remote sensing monitoring data in China. Nighttime light data were obtained from the 1000 m resolution dataset. For influencing factor data, economic factor data came from the corresponding years of the *China County Statistical Yearbook*. In the social factors, the number of health and social security practitioners came from the three population censuses, the number of primary school students came from the *China County Statistical Yearbook*, and the distance to prefecture-level cities was calculated based on latitude and longitude. In the natural factors, average annual rainfall and average annual temperature data came from 1000 m resolution national Earth grid data, and elevation data came from 500 m resolution global ocean bathymetry digital elevation model (DEM) data.

1.4 Methods

1.4.1 Shrinkage Identification and Evolution Classification Based on the constructed indicator systems for population, economy, and space, the shrinkage degree model for each dimension is calculated as follows:

$$S_k^{(t)} = \sum_{i=1}^{m} \left(\frac{X_{ik}^{(t)} - X_{ik}^{(t-1)}}{X_{ik}^{(t-1)}} \times W_i \right) \times 100\%$$

where: Taking population shrinkage as an example, $S_k^{(t)}$ is the population shrinkage index of county k in period t; m is the total number of population shrinkage indicators; $X_{ik}^{(t)}$ is the value of indicator i in the population dimension for county k in period t; W_i is the weight value of indicator i in the population dimension. To objectively and comprehensively describe the shrinkage degree of each county, it is necessary to standardize and classify the shrinkage degree. Here, considering relevant classification studies on county shrinkage degree and actual shrinkage changes, and based on relevant research on urban shrinkage in China, the shrinkage degree is divided into: severe shrinkage ($S_k^{(t)} < -0.3$), moderate shrinkage ($-0.3 < S_k^{(t)} < -0.15$), mild shrinkage ($-0.15 < S_k^{(t)} < 0$), and no shrinkage or growth ($S_k^{(t)} > 0$). The identification methods for economic and spatial dimension shrinkage are the same.

Meanwhile, to further identify the shrinkage evolution characteristics of each county, referring to relevant classification standards, the following four types are identified: continuous shrinkage type ($S_k^{(t)} < 0$ and $S_k^{(t-1)} < 0$), growth-to-shrinkage type ($S_k^{(t)} < 0$ and $S_k^{(t-1)} > 0$), shrinkage-to-growth type ($S_k^{(t)} > 0$ and $S_k^{(t-1)} < 0$), and continuous growth type ($S_k^{(t)} > 0$ and $S_k^{(t-1)} > 0$). Where $S_k^{(t)}$ and $S_k^{(t-1)}$ are the shrinkage indices of county k in periods t and $t-1$, respectively.

1.4.3 Multi-Index Comprehensive Evaluation Method The standardized values of each indicator in the criterion layer of county shrinkage in the agro-pastoral zone of northern China are multiplied by their weights and summed to obtain the population, economic, and spatial shrinkage indices, which are then weighted and summed to obtain the comprehensive shrinkage index. The specific calculation formula is:

$$US_c = \sum_{i=1}^{n} r_i W_i$$

where US_c is the comprehensive shrinkage measurement index of the agro-pastoral zone of northern China; W_i is the weight of indicator i; n is the number of indicators included in the criterion layer; and r_i is the quantified indicator value of indicator i for counties in the agro-pastoral zone of northern China.

$$US = \sum_{j=1}^{L} (US_c)_j W_j$$

where US is the comprehensive shrinkage measurement index of the agro-pastoral zone of northern China; $(US_c)_j$ is the shrinkage measurement index for population, economy, and space; L is the number of criterion layers; and W_j is the weight of the criterion layer elements.

1.4.4 Multiscale Geographically Weighted Regression (MGWR) Model Ordinary Least Squares (OLS) is the basic model for spatial modeling and analysis. To ensure the accuracy of the Geographically Weighted Regression (GWR) model, OLS is typically used for model variable diagnosis before constructing GWR. The formula is as follows:

$$Y_i = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i$$

where Y_i is the dependent variable corresponding to the i-th observation; $\hat{Y}_i$ is the predicted value of X; β_0 is the constant term; β_i is the regression coefficient for the i-th observation; and ε_i is the random error term for the i-th observation.

GWR introduces spatial relationships and is an improvement on the linear regression model. By introducing parameters that reflect geographical differences, it conducts differential regression on variables within local ranges, effectively avoiding errors caused by spatial differences in variables. The MGWR model introduces spatial scales on the basis of the GWR model, improves bandwidth selection, allows different variables to select different bandwidth values, and better reflects the spatial heterogeneity characteristics among variables, thereby improving the accuracy of regression analysis. The MGWR model formula is as follows:

$$Y_i = \sum_{j=1}^{K} \beta_{ij}(v_i)x_{ij} + \varepsilon_i$$

where Y_i is the dependent variable value at location i; x_{ij} is the independent variable at location i; K is the total number of spatial units participating in the analysis; ε_i is the random error term at location i; (v_i) are the spatial coordinates at location i; $\beta_{ij}(v_i)$ is the local regression coefficient for the j-th variable at location i. The larger the absolute value of the regression coefficient, the stronger its effect on the dependent variable.

2 Results

2.1 Shrinkage Identification and Evolution Characteristics

2.1.1 Analysis of Shrinkage Degree Population shrinkage is the most severe, with economy and space showing local shrinkage, and the overall trend demonstrates "encircling from the edge to the center." This shrinkage trend is particularly evident in the three northeastern provinces and eastern Inner Mongolia. From 2000 to 2020, both the degree and trend of shrinkage have significantly intensified. Specifically, the number of shrinking counties increased from 53 in 2000–2010 to 106 in 2010–2020, mainly located in the eastern and central parts of the study area (Figure 2). Among the three periods, mildly shrinking counties accounted for 19.81% and 13.21% of the total counties, respectively. Meanwhile, the number of moderately and severely shrinking counties increased substantially, rising by 36.79% and 33.96%, respectively. This phenomenon is related to the single industrial structure and resource depletion in Northeast China, as well as the weak economic foundation and fragile natural environment in Inner Mongolia, leading to decreased county vitality and severe population loss. Additionally, economic and spatial shrinkage show obvious synchronicity in temporal and spatial scales. However, while both economic and spatial shrinkage showed a continuous growth trend from 2000 to 2010, shrinkage phenomena emerged in the marginal areas of Inner Mongolia and the three northeastern provinces from 2010 to 2020. This is mainly because marginal counties lack diversified development momentum, and the siphoning effect of central cities restricts the development of surrounding economies, leading to shrinkage phenomena.

[Figure 2: see original paper] Spatial distributions of shrinkage degree of counties in agro-pastoral zone of north China from 2000 to 2020

2.1.2 Analysis of Shrinkage Evolution Overall, the evolution toward shrinkage follows the order of population shrinkage, spatial shrinkage, and economic shrinkage, with population shrinkage having the widest scope. From 2000 to 2020, the number of continuous shrinkage type and growth-to-shrinkage type counties accounted for 92.45% and 78.30% of the total cities, respectively, while the proportion of shrinkage-to-growth type cities was 7.55% and 21.70%, respectively. Although counties in the agro-pastoral zone of northern China have long invested heavily in industrial development and spatial utilization, they still cannot effectively prevent the trend of population loss. This is mainly because local economic development fails to match residents' expectations, resulting in insufficient income levels and quality of life, leading large numbers of residents to migrate to areas with greater development potential.

[Figure 3: see original paper] Spatial distributions of county shrinkage evolution in agro-pastoral zone of north China from 2000 to 2020

2.1.3 Multidimensional Combination Analysis Population loss not only impacts county economies but also has profound effects on spatial layout and land use. In the agro-pastoral zone of northern China, population loss is particularly severe, with shrinkage combinations dominated by population shrinkage becoming the main type. According to the combination relationships of shrinking counties across different dimensions (Table 2), only unidimensional population shrinkage was observed in 2000–2010. However, shrinkage types became more multidimensional in 2010–2020. Among two-dimensional shrinkage, population-space shrinkage dominates, followed by population-economy shrinkage. Among three-dimensional shrinkage, population-economy-space shrinkage accounts for 66.67% of the total multidimensional shrinkage. Multidimensional shrinkage is mainly concentrated in Inner Mongolia and Northeast China, with 89.62% of counties showing shrinkage, accounting for 66.67% of the total counties. The continuous shrinkage type is mainly distributed in some marginal counties and districts in central and eastern Inner Mongolia, where shrinkage phenomena are particularly evident (Figure 4). In the population dimension, 66.67% of counties show shrinkage. For a long time, the agro-pastoral zone of northern China has relied on agriculture, animal husbandry, heavy industry, and resource-based industries. While these provided strong impetus for local economies in the early development stage, over time, this excessive dependence and unreasonable land use patterns have gradually revealed their drawbacks.

[Figure 4: see original paper] Spatial heterogeneity of county shrinkage drivers in agro-pastoral zone of north China from 2000 to 2020

2.2 Analysis of Driving Factors

2.2.1 Selection and Testing of Influencing Factors Since there was no shrinkage in the economic and spatial dimensions from 2000 to 2010, the comprehensive shrinkage measurement index from 2010 to 2020 is used as the dependent variable to reflect shrinkage in the study area. To comprehensively analyze the influencing factors of county comprehensive shrinkage, the selected explanatory variables cover three levels: economic, social, and natural (Table 3). At the economic level, we selected total retail sales of consumer goods, completed fixed asset investment, local fiscal expenditure, and number of enterprises above designated size. Fixed asset investment, as a representative of infrastructure construction and production capacity improvement in the region, can effectively reflect the potential for economic development and expectations for future growth. Total retail sales of consumer goods directly reflect residents' consumption capacity and market activity, showing the current state of economic operation and residents' living standards. Local fiscal expenditure reflects government investment in infrastructure and public services. The number of enterprises above designated size is closely related to regional economic scale and modernization degree, reflecting industrial efficiency and its supporting capacity for employment. At the social level, we selected the number of health and social security practitioners, number of primary school students, and distance to prefecture-level cities as indicators to assess county public service levels, educational opportunities, and resource accessibility. At the natural environment level, we selected average annual rainfall, elevation, and average annual temperature to reflect regional climate conditions and topographic features.

Selection of driving factors

Multicollinearity tests were conducted on various influencing factors of county comprehensive shrinkage from 2010 to 2020. The Variance Inflation Factor (VIF) values were all less than 7.5, indicating no multicollinearity problems. The Moran's I index for comprehensive shrinkage from 2010 to 2020 was 0.312 ($P < 0.01$), indicating significant positive spatial correlation that enables geographically weighted regression analysis. Furthermore, to prove the rationality of model selection, OLS, GWR, and MGWR models were constructed to analyze the spatial effects of different influencing factors on comprehensive shrinkage measurement changes. Comparing the three model properties (Table 4), there are differences in model fitting results. Based on the corrected Akaike Information Criterion (AICc), residual sum of squares (RSS), goodness of fit (R^2), and adjusted goodness of fit (Adjusted R^2), the MGWR model has the largest R^2 (0.832) and the smallest AICc (1662.35), indicating strong explanatory power.

Comparison of regression properties of driving factors in OLS, GWR and MGWR models

2.2.2 Analysis of Regression Results The regression coefficients of the MGWR model can reveal the spatial response of influencing factors to comprehensive county shrinkage in the agro-pastoral zone of northern China. The absolute value of the average regression coefficient of local fiscal expenditure, fixed asset investment, and number of primary school students is higher than that of other factors, indicating that they play a dominant role in comprehensive county shrinkage (Table 5). Local fiscal expenditure shows a significant positive correlation with comprehensive county shrinkage. Higher local fiscal expenditure can, to a certain extent, inhibit comprehensive county shrinkage by increasing investment in infrastructure construction, public services, and social security, thereby enhancing local economic vitality and attracting population inflow. Meanwhile, the trend of "high in the southwest and low in the northeast" reflects regional economic development imbalance, resource allocation differences, and government policy orientation. Fixed asset investment in the agro-pastoral zone of northern China shows a significant negative correlation with comprehensive county shrinkage. Although fixed asset investment is usually regarded as an important driving force for economic growth, when investment is too concentrated in certain industries or regions, it may lead to resource waste and unreasonable industrial structure, further exacerbating population loss and economic recession in counties. This decreasing trend from northeast to southwest reveals that Northeast China faces greater pressure in the economic transformation process, making the positive effects of fixed asset investment insufficiently apparent. The number of primary school students shows a significant negative correlation with comprehensive county shrinkage, indicating that reasonable allocation of local educational resources can enhance regional attractiveness. With increasing awareness of education, parents attach significantly more importance to their children's education. However, the scarcity of educational resources leads to "scrambling" for these resources, meaning competition for quality educational resources among families becomes increasingly fierce. This competition not only intensifies the shortage of educational resources but also prompts some families to migrate to areas with richer educational resources, forming a significant spillover effect. In summary, the effects of various influencing factors on comprehensive county shrinkage show obvious regional differences, further emphasizing the importance of zonal management in mitigating county shrinkage in the agro-pastoral zone of northern China.

Statistics of regression coefficient in MGWR model

3 Discussion

Based on multidimensional perspectives of population, economy, and space, this paper analyzes the degree and evolution of county shrinkage in the agro-pastoral zone of northern China from 2000 to 2020. The spatial distribution of multidimensional shrinkage in this zone is closely related to natural conditions, resource reserves, and economic activities, indicating that shrinkage and growth is a complex, multidimensional process. The shrinkage spatial pattern and evolution characteristics of this region reflect the dynamic balance between population, economy, and space in different counties. Significant population loss has become the initial gap in county shrinkage in the agro-pastoral zone of northern China, severely inhibiting economic and spatial development in the region, particularly in Northeast China and Inner Mongolia where the impact is increasingly evident. To mitigate county shrinkage in the agro-pastoral zone of northern China, implementing a multi-level management system is crucial. The key to achieving this goal lies in narrowing development gaps between regions. Through zonal management, optimizing fiscal expenditures according to the actual needs of different regions, rationally adjusting investment structures, and improving the allocation efficiency of educational resources can effectively promote sustainable regional development and enhance population attractiveness. Additionally, optimizing management and policy formulation will provide more scientific theoretical basis and practical guidance for future regional development, ensuring a virtuous cycle between regional development and population flow.

4 Conclusions

1. The shrinkage phenomenon in the agro-pastoral zone of northern China is becoming increasingly severe, with obvious type differences. From 2000 to 2020, the agro-pastoral zone of northern China showed significant shrinkage trends in three dimensions: population, economy, and space. Population shrinkage was the most severe, with a growth rate of 64.15% and the widest coverage, followed by spatial shrinkage and economic shrinkage with growth rates of 30.19% and 7.55%, respectively.

2. County shrinkage in the agro-pastoral zone of northern China shows significant differentiation characteristics in time and space. Population loss has a significant impact on economic and spatial shrinkage. Overall, counties with comprehensive shrinkage and single-dimensional shrinkage in population, economy, and space are mainly concentrated in Northeast China and Inner Mongolia, showing a trend of "encircling from the edge to the center."

3. Shrinkage types are gradually becoming multidimensional. From 2000 to 2010, the agro-pastoral zone of northern China mainly exhibited unidimensional population shrinkage, while from 2010 to 2020, shrinkage types became more complex, encompassing two- and three-dimensional shrinkage, with population-space shrinkage as the dominant type.

4. According to MGWR model analysis, county shrinkage in the agro-pastoral zone of northern China is mainly influenced by local fiscal expenditure, educational resources, and fixed asset investment, with significant spatial differences among these driving factors. Therefore, implementing zonal management is crucial for achieving sustainable county development.

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