Evaluation and Prediction of Urban Shrinkage in Liaoning Province Based on Grey Theory

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Abstract. In order to ensure the sustainable and stable development of cities in Liaoning Province, aiming at the problem of urban shrinkage in Liaoning Province, this paper uses entropy weight method (EWM) and analytic hierarchy process (AHP) to preliminarily determine and moderately correct the weight of each index. The final weight of each index is completed by game theory, and the urban shrinkage evaluation model is established by multi-index comprehensive evaluation method to calculate the comprehensive shrinkage coefficient of Liaoning province. Then, in order to seek to shrink the relationship between urban economy, society and population, a grey correlation model is established. On this basis, the grey Markov prediction model is established to analyze the development and evolution trend of shrinking cities, and put forward reasonable scientific suggestions for urban development in Liaoning Province.

Keywords: Shrinking city · EWM-AHP · Combinatorial weighting · Grey correlation analysis

1 Discrimination and Classification of Shrinking Cities in Liaoning Province

1.1 Establish the Evaluation Model of Urban Shrinkage

In this section, the evaluation model of urban shrinkage is established according to the measurement of urban population. The model is mainly used to quantitatively measure the degree of urban shrinkage. Based on the previous research results, [1–3] the urban shrinkage degree measurement model is determined through comprehensive consideration. The population shrinkage degree of each city from 2007 to 2020 was calculated according to the following formula [4]:

$$S_{ip} = \left(X_{ip2007} - X_{ip2013}\right)/X_{ip2013} \tag{1}$$

J. Yen et al. (Eds.): ICBIS 2023, AHCS 14, pp. 597–607, 2023.
https://doi.org/10.2991/978-94-6463-198-2_61

$$S_{ip} = \left(X_{ip2020} - X_{ip2014}\right)/X_{ip2014} \tag{2}$$

where, S represents the population shrinkage degree of city i; X is the urban population of city i. According to the calculation results, if S is less than 0, it indicates that the city is in a state of contraction at this stage. Otherwise, it is a city with a constant or growing population.

1.2 Establishment of Evaluation Index System

(1) EWM is used to preliminarily determine the weights. First, data standardization is carried out, that is, for very large indicators and very small indicators. Then, the information entropy of each index is calculated. Finally, the weight of each index is determined based on the information entropy. The formula is as follows:

$$E_j = -\frac{1}{\ln n}\sum_{j=1}^{n} p_{ij} \ln p_{ij} \tag{3}$$

$$W_i = \frac{1 - E_i}{k - \sum_i Ei} \tag{4}$$

(2) The EWM compares the weight of each indicator by the confusion of the data itself, but according to the actual operation results, it has limitations and will be contrary to the fact [5]. In this paper, the AHP is applied to improve the evaluation system: the 9 indicators are classified and modified into the second-level indicators [6]. Firstly, the eigenvalues of the comparison matrix are calculated by using the weight vector, and then the consistency test is carried out to prevent the contradiction caused by arbitrary determination of weights.

(3) The basic method of combination weighting based on game theory is to seek Nash equilibrium, which can be achieved by finding the minimum deviation between the minimization weight combination and each basic weight [7]. First, we weight with n methods (formula 5). Second, according to the game theory aggregation model, the corresponding matrix is obtained. Based on the game theory aggregation model and the properties of differential equations, the corresponding linear equations are obtained (formula 6). According to (2), the matrix (column vector) (A1, A2…, An) for normalization.

$$W = \sum_{i=1}^{n} A_i \cdot W_i^T (A_i > 0) \tag{5}$$

$$\begin{bmatrix} W_1 \cdot W_1^T & W_1 \cdot W_2^T & \cdots & W_1 \cdot W_n^T \\ W_2 \cdot W_1^T & W_2 \cdot W_2^T & \cdots & W_2 \cdot W_n^T \\ \vdots & \vdots & \ddots & \vdots \\ W_n \cdot W_1^T & W_n \cdot W_2^T & \cdots & W_n \cdot W_n^T \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{bmatrix} = \begin{bmatrix} W_1 \cdot W_1^T \\ W_2 \cdot W_2^T \\ \vdots \\ W_n \cdot W_n^T \end{bmatrix} \tag{6}$$

The combination weights of nine second-level indicators are obtained by game theory combination weighting. This result avoids subjectivity and is more scientific and convincing, as shown in Table 1:

Table 1. Index weight of different methods.

	method of endow with weight	EWM	AHP	combination weight
social dimension	public basic protection	0.080	0.065	0.085
	expenditures in the general public budget	0.095	0.075	0.080
	total retail sales of consumer goods	0.107	0.097	0.097
economic dimension	increasing rate of GDP	0.090	0.086	0.085
	PERGDP	0.095	0.090	0.095
	investment in real estate development	0.106	0.128	0.126
	fixed investments	0.137	0.146	0.127
population dimension	urban population of Liaoning	0.162	0.168	0.169
	employment in the secondary and tertiary industries	0.128	0.145	0.136

1.3 Multiindex Comprehensive Evaluation Method

By multiplying the standardized value and weight of the urban shrinkage criterion layer (the first-level index layer) in Liaoning Province, the urban population, economic, and social shrinkage index of Liaoning Province is calculated, and then the comprehensive shrinkage coefficient of Liaoning Province is obtained by weighted summation. First, the measurement coefficient US_c of urban shrinkage criterion layer is calculated (formula 7). Second, based on the US_c, the measurement coefficient of urban shrinkage is further calculated in this paper (formula 8).

$$US_c = \sum_{i=1}^{n} r_i w_i \tag{7}$$

$$US = \sum_{j=1}^{m} (US_c)_j w_j \tag{8}$$

1.4 Discrimination and Classification of Shrinking Cities in Liaoning Province

(1) The discrimination of shrinking cities. Based on the above model, this paper analyzes the scale evolution of county-level cities in Liaoning Province and identifies the shrinkage phenomenon. The original data selected by this paper are all from China Statistical Yearbook Service System. From 2007 to 2013, only 4 county-level cities had urban shrinkage phenomenon. In the following six years, the urban shrinkage of Liaoning Province intensified. From 2014 to 2020, three prefecture-level cities contracted, and 19 county-level cities had urban shrinkage phenomenon. That means more than 93.7% of cities in Liaoning Province experienced urban shrinkage in the second stage, almost covering all county-level cities.

Table 2. Classification criteria for urban shrinkage.

classification of shrinkage	severe shrinkage	moderate shrinkage	mild shrinkage	critical or growing
shrinkage index	S < −0.2	−0.2 ≤ S ≤ −0.05	−0.05 ≤ S < 0	0 ≤ S

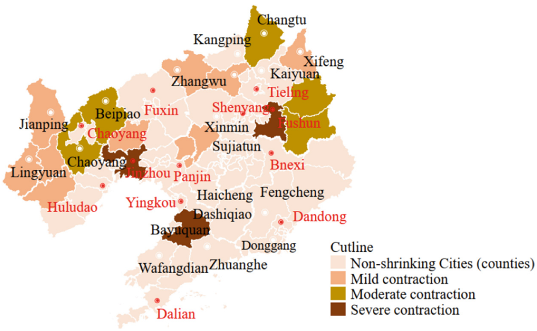


Fig. 1. Schematic diagram of urban shrinkage pattern in Liaoning Province from 2007 to 2013.

(2) Classification of shrinking cities. Based on the discrimination of cities in Liaoning Province, according to the different degrees of shrinkage, the shrinkage cities are divided into three categories, such as mild shrinkage (−0.05 ≤ S < 0), moderate shrinkage (−0.2 ≤ S ≤ −0.05), and severe shrinkage (S < −0.2). As shown in Table 2.

For the time dimension, we divide the urban shrinkage of Liaoning Province into two stages from the temporal evolution [8]. In the first stage (2007–2013), there are only 4 county-level cities in the shrinking state, accounting for 25% of the total number of county-level cities, and generally mild contraction. For the spatial dimension, in the first stage (the initial shrinkage), the shrinking cities first appeared in the eastern mountainous area and the northwest area. However, in the second stage (the large-scale shrinkage), a large number of cities and counties located outside the metropolitan area of Shenyang, the capital of Liaoning Province, showed different degrees of shrinkage. As shown in Figs. 1 and 2.

2 Study on Population, Economic, and Social Development in Shrinking Cities

2.1 Grey Correlation Analysis Based on Coupling Index System

(1) Based on the theoretical framework of urban shrinkage evaluation, this paper decomposed the population change system from three aspects: natural growth rate, population migration rate and the number of people employed in the secondary and tertiary industries. In the economic and social system, six ii-level indicators were selected, including per capita GDP, general public budget expenditure, fixed asset investment, total retail

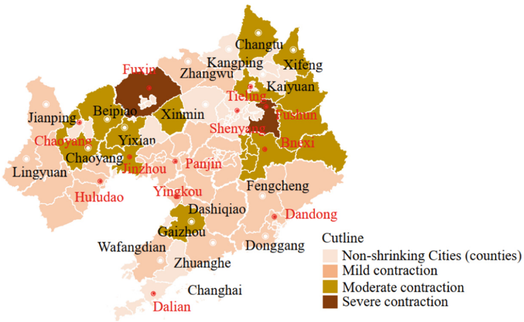


Fig. 2. Schematic diagram of urban shrinkage pattern in Liaoning Province from 2014 to 2020.

sales of consumer goods, total industrial output and infrastructure level. The coupling index system of population change system and economic and social system is constructed by using two level II indexes, and the correlation degree of population change is analyzed by using grey correlation. The index system of population change and socio-economic coupling in Liaoning Province is shown in Table 3.

(2) Grey correlation analysis (GRA) is an analytical method based on the theory of grey system. [9, 10]. First, we select the data of population structure system (X_i) and economic system (Y_j) as the analysis sequence. Second, the standard deviation method

Table 3. Coupling index system of population change and economic and society in Liaoning Province.

first grade indexes	second index	unit	first grade indexes	second index	unit
population change system	X1 natural increase rate	‰	socioeconomic system	Y1 per capital GDP	yuan
				Y2 general public budget expenditure	100 million yuan
	X2 population migration rate	‰		Y3 fixed asset investment	100 million yuan
				Y4 total retail sales of social consumer goods	100 million yuan
	X3 number of employment in the secondary and tertiary industries	ten thousand people		Y5 total industrial output value	100 million yuan
				Y6 infrastructure level	100 million yuan

was used to standardize the original data to obtain X'$_i$ and Y'$_j$. Thirdly, the correlation coefficient is calculated (formula 9).

$$R_{ij}(t) = \frac{\min\limits_i \min\limits_j \left|X_i'(t) - Y_j'(t)\right| + \rho \max\limits_i \max\limits_j \left|X_i'(t) - Y_j'(t)\right|}{\left|X_i'(t) - Y_j'(t)\right| + \rho \max\limits_i \max\limits_j \left|X_i'(t) - Y_j'(t)\right|} \quad (9)$$

Finally, the correlation degree is calculated (formula 10) and then the coupling degree is calculated. The correlation degree model of system coupling is obtained by the correlation degree matrix.

$$\gamma_{ij} = \frac{1}{k}\sum_{i,j=1}^{k} R_{ij}(t) \quad (10)$$

where, γ_{ij} is the correlation degree and k is the sample data. The value range of γ_{ij} is 0–1.

2.2 Coupling Analysis of Population Change and Economic Development

(1) Using the correlation coefficient formula, the correlation matrix of population change and economic and social coupling is calculated, as shown in Table 4. The results show that the correlation between population change and economic and social indicators is above 0.6, which belongs to moderate and high correlation. The impact of economic society on population change is relatively balanced, and the correlation between the indicators is not much different. Fixed asset investment has the greatest impact on population change, and the correlation coefficient is 0.758. This shows that the degree of industry, employment and enterprise investment has a greater impact on population change in Liaoning Province. Followed by the total industrial output value and infrastructure level, the correlation were 0.753 and 0.750, respectively.

(2) In order to further analyze the changes in the time dimension of the coupling degree between population structure and economic society, we calculated the coupling degree from 2007 to 2020, as shown in Fig. 3. Based on the results, this paper divides the coupling degree into two stages: 2007–2013, an upward trend; 2014–2020, a downward trend. From 2007 to 2010, the coupling degree was distributed between 0.468 and 0.745. From 2010 to 2013, the coupling degree increased from 0.568 to 0.742, reaching the

Table 4. Correlation coefficient and correlation degree of population change and economic and social coupling in Liaoning Province.

index	X1	X2	X3	mean value	index	X1	X2	X3	mean value
Y1	0.752	0.679	0.761	0.730	Y4	0.747	0.670	0.799	0.739
Y2	0.685	0.692	0.791	0.723	Y5	0.753	0.737	0.768	0.753
Y3	0.806	0.709	0.759	0.758	Y6	0.806	0.682	0.761	0.750

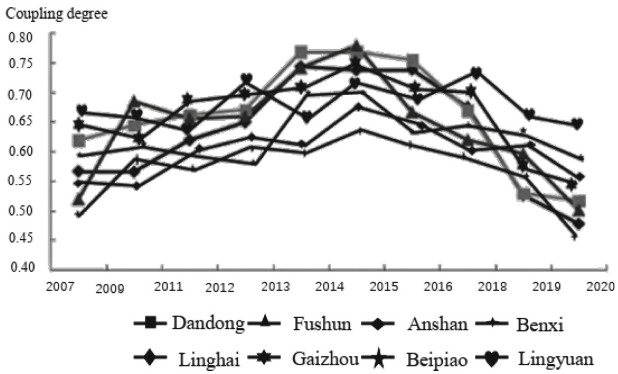


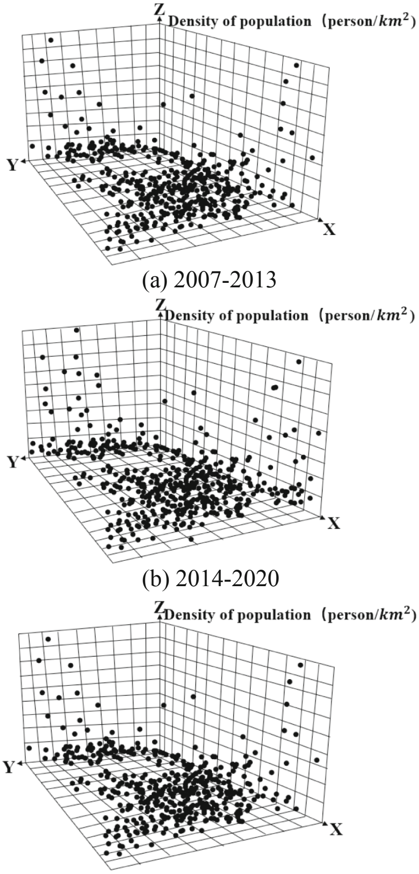
Fig. 3. The coupling degree of population change and economic society in shrinking cities from 2007 to 2020.

highest value, indicating that the population change and economic society were in the stage from antagonism to running-in. The reason may be that before 2010, the GDP growth rate of Liaoning Province increased year by year, the economic development level was good, and the labor resources were rich.

3 The Development and Evolution Trend of Shrinking Cities

On the basis of grey correlation, the grey prediction model and Markov chain model are established. The grey prediction model and Markov chain model together constitute the grey Markov prediction model. The multi-dimensional grey Markov prediction model is established according to the introduction of population dimension, economic dimension and social dimension, and then the evolution trend of different shrinking cities is obtained by solving the model. It is not difficult to find that the population loss of shrinking cities in Liaoning Province from 2007 to 2013 is less. The possible reason is that Liaoning has carried out urbanization and developed heavy industry and primary and secondary industries. However, the population loss is serious from 2014 to 2020, and the population change will not change much from 2021 to 2025. For details, see Fig. 4.

In the eight identified cities with shrinkage, the urban shrinkage was significantly aggravated from 2007 to 2013 and from 2014 to 2020. However, it is expected that some cities will be improved from 2021 to 2025. Urban shrinkage is an inevitable problem for the development of global cities, but urban shrinkage does not mean absolute economic and social decline. The improvement of infrastructure and public services is the guarantee of urban development, so as to create a good working environment for the society and promote the development of enterprises. Improve cities ' resilience and sustainability by reducing their size precisely. Based on the development of different types of cities, people comprehensively examine and study the scope and feasibility of urban growth, and assess the possibility of re-development of shrinking cities. Trend surface of population density in Liaoning Province are as shown in Fig. 5.



(a) 2007-2013

(b) 2014-2020

(c) 2021-2025

Fig. 4. Trend surface of population density in Liaoning Province.

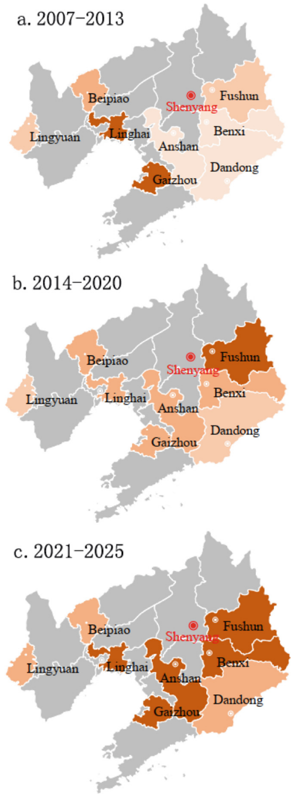


Fig. 5. Trend surface of population density in Liaoning Province

4 Conclusion

Based on the phenomenon of urban shrinkage in many cities in China, we takes 14 prefecture-level cities in Liaoning Province as the research object. We select the corresponding indicators from the three dimensions of population, economy and society. Then the evaluation system of urban shrinkage is constructed by game theory combination weighting in order to identify and predict the shrinking cities in Liaoning Province. In addition, we analyzes the coupling degree and correlation degree of economic and social development level in Liaoning Province by using the grey correlation of coupling index system. The main influencing factors of the interaction between population change and economic society are obtained. It provides substantive help for its next planning, and also provides a reference for solving the problems currently facing shrinking cities in China. The specific conclusions of this paper are as follows:

(1) Urban shrinkage in Liaoning Province is serious. More than 60% of the cities are shrinking, and the northern part of Liaoning Province has a higher degree of shrinkage.

(2) The population change and economic and social development factors of shrinking cities promote and restrict each other. Normal population growth rate and high employment can promote economic and social development, otherwise it will hinder economic and social development.

(3) The impact of economic and social development on shrinking urban population is relatively balanced. GDP per capita and general public budget expenditure have a greater impact on population change, followed by infrastructure level and total retail sales of social consumer goods.

(4) From 2007 to 2013, the population loss of shrinking cities in Liaoning Province is relatively small. The possible reason is that Liaoning Province has vigorously developed the heavy industry and the primary and secondary industries. However, in 2014–2020 the population loss is serious. Population changes will not change much in 2021–2025.

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