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Spatio-temporal Evolution of the Rural Regional System and Its Evolution Mechanism in Huang-Huai-Hai Area of China

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Abstract: The problem of rural development arises from the evolution of rural regional system. It is urgent to deepen the research on the evolution process and mechanism of rural regional system. However, there are relatively few studies on rural development from the perspective of the evolution process, driving mechanism and evolution mechanism of rural regional system. Therefore, this study took Huang-Huai-Hai Area for example, started with the systematicness of the rural regional system, the spatio-temporal pattern and driving mechanism of rural regional system evolution, and further summarized and refined the evolution mechanism of the rural regional system. The methods of spatial pattern analysis, gray correlation degree and geographical detection were adopted. The results showed that the problems in rural areas were often dominated by one factor and produced by the joint action of many factors. Factors such as county urbanization, county economy, county public service, agricultural mechanization, surrounding cities and convenient transportation will affect the evolution of rural regional systems. Based on the evolution of the elements in the rural regional system, the evolution types of rural regional system can be divided into decline type, equilibrium type and growth type. This study can provide a reference for understanding the process of rural rise and fall and can also guide rural revitalization and rural sustainable development.

Keywords: rural evolution; rural regional system; population-land-industry; evolution mechanism; rural revitalization; Huang-Huai-Hai Area (HHHA)

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1 Introduction

The excessive concentration of various factors in urban areas makes the world's rural areas face a declining trend (Liu and Li, 2017; Ayala et al., 2021). According to the World Bank, the world urbanization rate increased from 33.62% in 1960 to 54.83% in 2017, 21.21% in 57 years, with an average annual growth of about 0.37%, which means that more and more people around the world will live in cities (https://data.worldbank.org/region/world). Since China's reform and opening-up, China's urbanization and industrialization have developed rapidly. At the same time, China's connection with the world has also been strengthened. In this macro context, China's rural regional structure, spatial pattern, and industrial model have undergone significant changes (Liu, 2018a). The new rural construction and targeted poverty alleviation strategies promote the initial improvement of rural public services and infrastructure (Chen et al., 2018). However, the pattern of 'urban development and village decline' has not changed (Li et al., 2018a). The decline of the rural regional system and

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'rural diseases' are becoming more and more serious (Liu, 2018b). The essence of 'rural diseases' is the manifestation of the disorder, anomie, and degradation of rural regional system evolution. Therefore, it is urgent to deepen the research on the process and mechanism of rural regional system evolution.

At present, there are more researches on rural static states, but less on evolution of the rural regional system. The researches related to the evolution of the rural regional system mainly focus on rurality (Li and Zhang, 2015), rural reconstruction (Tu et al., 2018), and rural transformation (Li et al., 2018b). The concept of rurality is opposite to urbanity, which was first put forward by Cloke. He selected indicators and constructed the evaluation method of rurality by principal component analysis, and classified the villages in England and Wales according to rurality (Cloke, 1977). The rurality was proposed to answer the question of 'what are the rural areas' (Braga et al., 2018). Based on the concept of rurality, scholars construct indicators for empirical analysis. Some scholars use the method of social representation to study rurality, that is, they pay attention to how different groups understand rurality and what roles different groups play in rurality, and what discourse power they have (Fan and Zhu, 2016; Lundgren and Johansson, 2017). The focus on rurality has experienced a change from the material level to the imaginary level, which focuses on the qualitative interpretation of the formation mechanism (Lv and Lin, 2017; Shen et al., 2019). Chinese scholars have done much research on rural quantitative evaluation, mainly selecting different cases to build the index system for empirical research (Long et al., 2009; Feng et al., 2018). After the 1950s, some developed countries experienced the process of urbanization and counter urbanization, which led to significant changes and reconstruction in many aspects of rural areas (Long and Tu, 2017). In the early stage of rural reconstruction research, due to the concern about the production function of rural areas, agriculture and rural areas were often associated(Wilson, 1995; Hoggart and Paniagua, 2001). Subsequently, the understanding of the countryside became more diverse, and the research on rural population (Hedlund and Lundholm, 2015), social imagination (Phillips, 1998), environment (Nelson, 2001), policy (Douglas, 2005), and so on began to rise. Besides, the reconstruction of rural settlements' spatial organization (Wang et al., 2016a; Tian et al., 2018) and rural industry (Zhang et al., 2022) are also studied. Chinese scholars mainly focus on the relationship between land consolidation and rural reconstruction (Hu et al., 2018), the reconstruction of the rural economy (Mao, 2017), the reconstruction of rural social culture in the process of urbanization (Tao et al., 2015), and so on. The rural transformation was proposed by Liu, which is mainly used to analyze the rural transformation from the perspective of the relationship between urban and rural areas (Liu, 2007). Meanwhile, the traditional industry, employment mode, and consumption mode in rural areas have changed in the process. Rural transformation is to realize the integration of urban and rural development, accompanied by population transfer, resource redistribution, and industrial transformation (Yang et al., 2018). Subsequently, the research on rural transformation mainly constructs the index system from the perspective of population-land-industry, such as the proportion of the non-agricultural population, the proportion of construction land, the non-agricultural rate, *etc*., and the transformation coupling degree, coordination deviation degree, coordination transformation degree, and other models were introduced (Wang et al., 2016b; Li et al., 2018).

With the proposal and implementation of rural revitalization, the evolution of rural regional system began to receive attention. Some scholars analyzed the change of rural human-land relationship from the relationship between rural population change and land resource change (Li et al., 2020). In addition, some scholars have also discussed the types of rural areas in China and the ways of village zoning (Zhou et al., 2020), and put forward the classified guidance strategies for rural development (Liu et al., 2019). However, such studies are still partial to static type division, and focus on the national scale, lack of guidance for rural regional types in specific type areas, and relatively do not pay attention to the evolution law of rural regional system types.

The evolution of the rural regional system is the process of the rural regional system from one state to another. Rurality was proposed to answer the question 'what are the rural areas'. It was often used to divide the rural types. There is a clear social and cultural tendency in the research of rural reconstruction. The research of rural reconstruction pays more attention to rural ontology. Its main concern is the changes of various elements in rural areas. The concept of rural transforma-

tion was proposed from the perspective of the urban-rural relationship, which pays more attention to the evolution process of rural to urban transformation. However, the evolution of rural regional system mainly refers to the interaction between rural areas and urban areas in the process of their own evolution, which contains the connotation of changes within rural areas and urban-rural relations. Therefore, the evolution of rural regional system is more in line with the current reality of urban-rural development, and its systematic cognition can better guide rural development.

As a complex system, the rural regional system should be studied comprehensively from the perspective of the human-land relationship system (Liu, 2020). Though some scholars have discussed the evolution mechanism of rural settlement spatial patterns, the existing research on the evolution mechanism of the rural regional system is relatively few (Yang et al., 2016; Chen et al., 2022). There are also some scholars from the theoretical perspective to explore the reasons why the countryside can rise and fall (Li et al., 2019). However, there are relatively few studies on rural development from the perspective of the evolution process, driving mechanism, and evolution mechanism of the rural regional system. Therefore, this study took Huang-Huai-Hai Area for example, analyzed the evolution process and mechanism of the rural regional system from a systematic perspective. The present study had the following objectives: 1) to analyze the evolution process of the rural regional system from the perspective of systematicness; 2) to analyze the key driving factors affecting the evolution of the rural regional system; 3) to construct the evolution mechanism of the rural regional system from the systematic perspective. This study can provide a basis for understanding the evolutionary process of the rural regional system, and can also guide rural revitalization and sustainable development.

2 Materials and Methods

2.1 Study area

China's Huang-Huai-Hai Area (HHHA) (32°N–40°N, 114°E–121°E) spans six provinces including Tianjin, Hebei, Shandong, Henan, Anhui, Jiangsu and one municipality directly under the Central Government, Beijing, covering an area of about 410 000 km^2 (Fig. 1).1) The counties in HHHA play an important role in grain production. In 2015, the total grain output of the county where HHHA is located accounted for about 24% of the country's total grain output, which is a typical representative of China's nine major agricultural regions (Hou et al., 2020). Agriculture is the core industry in rural areas of HHHA.From 2000 to 2015, the county's total grain output increased by about 43 million t, and the total power of agricultural machinery increased by about 147 million kilowatts. 2) The rapid decrease of rural population coexists with the expansion of homestead area. At the same time, the increase of non-agricultural population and the decrease of cultivated land coexist, and the contradiction between humans and land is prominent. From 2000 to 2015, the rural resident population of HHHA decreased from 167 million to 135 million, a decrease of about 32 million, with an average annual outflow of 2.13 million; the number of rural employed people in 2000 and 2015 was 94 million and 102 million respectively, with an average annual increase of about 530 000. In 2000 and 2015, the area of cultivated land in HHHA County was 25 826 and 257 936 km^2 respectively, with an average annual decrease of about 26 km^2; rural residential land increased sharply, with an average annual increase of about 127 700 km^2 in 2000 and 41 600 km^2 in 2015 (National Bureau of Statistics, 2018). 3) In the process of rapid development of urbanization and industrialization, the loss of cultivated land resources, waste of land resources and other resources and environmental problems brought about by the transformation of production and lifestyle are prominent. Rural diseases restrict the sustainable development of rural areas. Therefore, it is typical and representative to regard this area as the case.

2.2 Methods

2.2.1 Index system

In this study, we mainly discuss the factors of obvious changes in the rural regional system under the background of urbanization, industrialization, and changes in people's production and life, and explore their influencing factors. Therefore, this study mainly discusses the evolution of the rural regional system from the aspects of rural population, land, and industry (Table 1). The selection basis of the index system will be further explained in detail as follows.

Rural population is the basis of the development of rural areas. The rise and fall of the rural population are

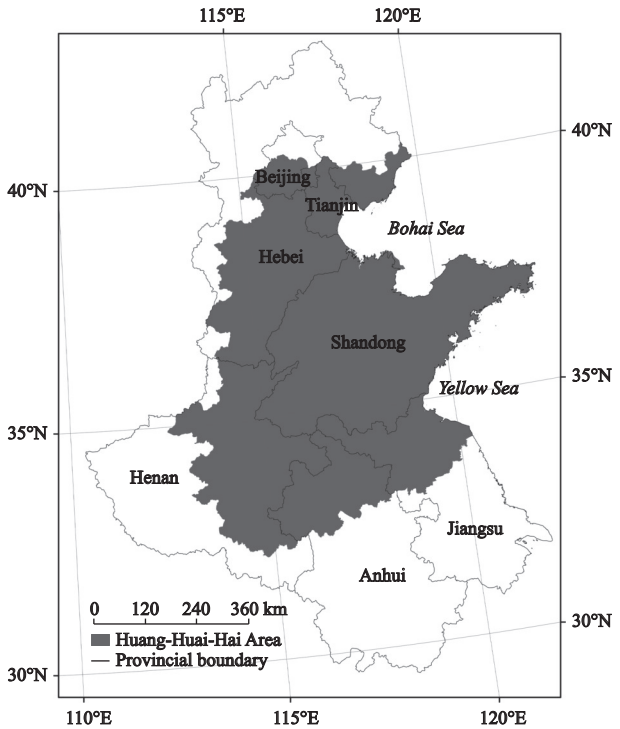

Fig. 1 Location of Huang-Huai-Hai Area, China

related to the long-term development of rural areas. Rural population density is a direct reflection of the population distribution in rural areas, of which evolution can directly reflect the 'rise and fall' process of the population in a region (Zhang and Yang, 2019). Therefore, the rural population density was selected as one of the indicators to reflect the population evolution. The income of rural residents is the basic guarantee of farmers' livelihood, which mainly comes from farming income and part-time income. For rural residents, the secondary and tertiary industries often have higher output value than the primary industry. The higher the level of rural residents engaged in the secondary and tertiary industries, the higher the income level, to narrow the gap between rural residents' income and urban residents' income (Huang et al., 2020). Therefore, the rural non-agricultural employment rate was selected to reflect the level of part-time employment of rural residents. This study selected rural population density and rural non-agricultural rate to reflect the development of the rural population.

Cultivated land is closely related to the development of farmers. In areas where the average output value is relatively consistent, the abundance of cultivated land resources determines the income of farmers. Some scholars pointed out that the enrichment of cultivated land resources may also contribute to the poverty trap (Li et al., 2021). However, the enrichment of cultivated land resources has increased the per capita occupation of cultivated land resources, which provides a basis for large-scale land management in the future. Under the background that a large number of farmers are going to work in cities, cultivated land may become a burden on the increase of farmers' income. However, with the large loss of rural population in the future, the increase of per capita cultivated land resources and the change of farming mode, cultivated land resources will still become one of the core resources for rural development. Therefore, per capita cultivated land area can effectively measure the abundance of rural cultivated land resources. Homestead is the carrier of rural residents' living place. Due to the loss of rural population and the rel-

Table 1 Index system of rural regional system evolution

Target layer	Rule layer	Index layer	Index description	Weight
Rural regional system	Rural population (1/3)	Rural population density (X_1)	Rural resident population / non urban land area	0.51
		Rural non-agricultural employment rate (X_2)	Rural non-agricultural employed population / rural permanent resident population	0.49
	Rural land (1/3)	Rural cultivated land area per capita (X_3)	Cultivated land area / rural resident population	0.56
		Rural homestead area per capita (X_4)	Rural residential land area / rural permanent population	0.44
	Rural industry (1/3)	The output value of rural primary industry per capita (X_5)	The output value of primary industry / rural permanent population	0.65
		The proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land (X_6)	(Primary output value / cultivated land area) / (secondary and tertiary output value / urban construction land area)	0.35

Notes: The weight of all indexes was calculated by the entropy weight method (Cheng, 2010). Rural population, land, and industry were calculated by equal weight 1/3

atively loose supervision of rural housing foundation construction, the problem of 'hollowing village' was caused. A large number of homestead vacancies caused by 'population leaving with land idle' have caused a serious waste of land resources. Therefore, the per capita residential land area in rural areas can be used to measure the land intensity of rural settlements. However, there is a negative correlation between the two, that is, the larger the per capita residential land area is, the lower the degree of land-intensive use is, and vice versa. In this study, the per capita cultivated land area and the per capita homestead area were selected to reflect the rural land.

Rural areas are dominated by the primary industry. The development of the primary industry is closely related to the rural industry development. The higher the per capita output value of the primary industry in rural areas, the easier it is for residents to get enough income to support a family through primary industry, thus avoiding the loss of population in rural areas (Cheng et al., 2019a). Therefore, the output value of rural primary industry per capita could be used to reflect the rural industry development. Besides, the land average difference of industrial output value between urban and rural areas will lead to the agglomeration of rural resources to the city. Improving the land average output value of rural areas is an important way to effectively improve the economic level of rural areas, and can also avoid the excessive concentration of resources to urban areas. Therefore, the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land was selected to reflect the development efficiency of the rural economy. This study selected the output value of rural primary industry per capita, the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land to reflect the development of the rural industry.

Evolution involves the starting point and the endpoint of the development of things, and the mechanism of evolution is usually determined by the state of the starting point of things. The rural regional system evolution annual rate and its influencing factors can be calculated by Equation (1).

$$RY = \frac{\Delta Y}{\Delta t} \times \frac{1}{Y_t} \times 100\% = \frac{Y_{t+1} - Y_t}{\Delta t} \times \frac{1}{Y_t} \times 100\% = f(X_{it1}, X_{it2}, X_{it3}, \ldots X_{itn}) \quad (1)$$

where RY is the evolution rate of the rural regional system; ΔY is the change of rural regional system in a time cycle; Δt is an evolution cycle; Y_{t+1} is the state value of the rural regional system at time $t + 1$; Y_t is the state value of the rural regional system or one of its elements at time t; X_{it1}, X_{it2}, X_{it3} …, X_{itn} is the state value of the influencing factors at time t, n is number of factor, that is, the factors influencing the evolution in an evolution cycle are determined by the state of the influencing factors at the starting point.

The influencing factors of rural regional system evolution include many factors. Urban areas often play a role of growth pole in regional development, and rural development is also related to the cities. The development of county urbanization has an important impact on the development of population and industry in rural areas. The development of urbanization in a region leads to the loss of population and occupation of cultivated land resources in rural areas on the one hand, and also realizes the nearby employment of farmers to avoid the loss of land resources (Cheng et al., 2019b). Therefore, the urbanization rate would have an impact on the evolution of the rural regional system. Per capita GDP is a direct reflection of the overall economic development level of a region. The higher the overall level of regional development, rural development will be more affected by the regional development dividend. Besides, the improvement of the regional economic development, the increase of farmers' income will promote the willingness of farmers to return to the countryside and build houses. If the government failed to control it in time, the land for rural homestead will appear a waste situation (Yang et al., 2019). Therefore, the development level of per capita GDP in the county would have an impact on the evolution of the rural regional system. The development of the county industry improves the level of county economic development, but it also brings more employment opportunities. The county industry can not only affect the development of rural areas through the improvement of the overall environment of the county but also affect the population flow in rural areas through the improvement of employment opportunities. Therefore, the per capita gross output value of industries

above designated size would have an impact on the evolution of the rural regional system. Local budget revenue reflects the level of government revenue in a region. The higher the government revenue, the more funds can be used for county development and county policy implementation. Under the strategic background of urban-rural integration and rural revitalization, the per capita local budget revenue would also affect the development of the rural regional system. The infrastructure investment reflects the completion of infrastructure investment in the county, which is the basis of economic development. The more active the infrastructure investment is, the more active the county's economic development is, which would also have an impact on the evolution of the rural regional system. With the development of the social economy, more and more attention has been paid to the quality of the population. The improvement of the quality of the population plays an important role in improving family income and promoting the transformation of farmers' employment (Haas and Westlund, 2018). The improvement of the quality of the population would play an increasingly important role in the evolution of the rural regional system (Karahasan and Bilgel, 2021). Therefore, this study selected the proportion of students in school to reflect the development level of the quality of the population in a region. The more developed the social public service, the more residents can enjoy the full social life security. This study selected the number of social welfare adoptive beds per capita in the county and the number of medical and health beds per capita in the county as two of the factors to reflect the development of social public service. The degree of mechanization is very important for the development of rural industry, which can not only reduce the amount of labor input but also improve the efficiency of unit labor (Takeshima et al., 2020). Therefore, this study selected the average total power of agricultural machinery to reflect the development of rural agricultural mechanization. The influence of the city on rural areas tends to decrease with the increase of distance, showing a decreasing law with the increase of distance (Goodchild, 2009). With the development of transportation technology, the commuting distance is often more practical than the actual distance (Ye et al., 2020). Therefore, the commuting distance to the city could be selected to reflect the distance between the research unit and the cities. The greater the density of the road network in an area, the shorter the distance of the external connection. On the one hand, the external connection will lead to the loss of population in rural areas. On the other hand, the increase of external connection will facilitate the circulation of rural production products, thus driving the development of the rural economy (Sewell et al., 2019). Therefore, the road network density would also have an impact on the evolution of the rural regional system. These factors can be further summarized into six categories: county urbanization, county economy, county public service, degree of agricultural mechanization, distance to the city, and transportation convenience (Table 2).

2.2.2 *Moving average curve*

In order to explore the relationship between the development of rural regional system and its elements, we need to know the change trend of its elements with the improvement of the development level of rural regional system. However, the scatter diagram of the development level of rural regional system and the development level of its elements is often chaotic, which makes it difficult to find the change law between them. Therefore, it is necessary to convert the scatter diagram into a smooth curve through the moving average method to more intuitively reflect the change trend of various elements. According to the total number of samples (about 1000), the 20 cycle moving average curve is finally determined as the appropriate simulation curve. The moving average algorithm used in this paper can be calculated by Equation (2).

$$f(RS_t) = (RS_{t-1} + RS_{t-2} + RS_{t-3} + \ldots + RS_{t-20})/20 \quad (2)$$

where RS_t is the predicted value of rural regional system at time t; RS_{t-1}, RS_{t-2}, RS_{t-3}, …, RS_{t-20} are the actual value of $t-1$, $t-2$, $t-3$,…, $t-20$; 20 is the number of moving average periods.

2.2.3 *Gray correlation method*

Gray correlation analysis is a method of reflecting the degree of correlation between different factors by analyzing the degree of similarity or dissimilarity of values between different factors. When the gray correlation degree is higher, the correlation between the two factors in a system is stronger. On the contrary, it indicates that the relevance is weak. The gray correlation degree can quantitatively describe the degree of correlation between the development of rural regional system and the

Table 2 Factors influencing the evolution of the rural regional system and its explanation

Types	Influence factors	Index explanation
County urbanization	Urbanization rate of county (Z_1)	Urban resident population / county resident population
County economy	GDP per capita (Z_2)	GDP / County resident population
	Gross output value of industries above designated size per capita (Z_3)	The gross output value of industries above Designated Size / resident population of the county
	Local budget revenue per capita (Z_4)	Local budget revenue / County resident population
	Capital construction investment per capita (Z_5)	Infrastructure investment completed / County resident population
County public service	The proportion of students in school (Z_6)	Number of students in school / County resident population
	Number of social welfare adoptive beds per capita in the county (Z_7)	Number of social welfare adoptive beds / County resident population
	Number of medical and health beds per capita in the county (Z_8)	Number of medical and health beds / County resident population
Degree of agricultural mechanization	Average total power of agricultural machinery (Z_9)	Total power of agricultural machinery / cultivated land area
distance to the city	The shortest distance to the city (Z_{10})	Distance to nearest prefecture-level or provincial capital city
transportation convenience	Road network density (Z_{11})	Length of road network per unit area

driving factors, form a comprehensive understanding of the whole driving system, so as to distinguish which factors are the main driving factors, and provide a reference for further analysis of the strength of the main driving factors. This study is mainly used to explore the relationship between the evolution of rural regional system and its various elements (ΔZ_1, ΔZ_2, …, ΔZ_6) and influencing factors (Z_1, Z_2,…, Z_{11}). Due to the maturity of the gray correlation method and the limited space, this paper will not repeat its calculation formula.

2.2.4 Geographic detector

After determining the range of key driving factors for the evolution of rural regional system by gray correlation analysis method, in order to explore the action intensity of key driving factors, geographic detector method is used to analyze the action intensity of each key driving factor. The geographic detector is built on the assumption that if one geographical element has an important impact on another geographical element, the spatial distribution of the two geographical elements should be similar. It can be used to detect spatial differentiation and its driving mechanism. This study used this model to detect the impact of various driving factors on the evolution of rural regional system. This can be calculatedby Equation (3).

$$q = 1 - \frac{1}{N\delta^2}\sum_{h=1}^{L} N_h {\delta_h}^2 \tag{3}$$

where q is the effect intensity of each driving factor on the evolution of rural regional system; N_h is the number of samples in the type of each driving factor; N is the number of samples in the whole study area (in this study, it is the number of counties in the HHHA); L is the number of categories for each driving factor; δ^2 is the discrete variance of the entire area; δ_h is the variance of the type county h of each driving factor. The value range of q is [0, 1]. When q = 0, it shows that the evolution of county rural regional system is not affected by driving factors; when q = 1, each driving factor plays a decisive role in the spatial differentiation of rural regional system evolution; the larger the q, the greater the impact of the driving factors on the spatial differentiation of the evolution of the rural regional system.

2.3 Data

The data involved in this study were mainly from the fifth national census (2000) and the sixth national census (2010) (http://www.stats.gov.cn/tjsj/tjgb/rkpcgb/), China Statistical Yearbook (county-level) (2001; 2011; 2016) and the Provincial Statistical Yearbook (2001; 2011; 2016) (https://nianjian.cnki.net). The land data were mainly from the land data of earth system science data sharing platform of Institute of Geographical Sciences and resources, Chinese Academy of Sciences in 2001, 2011, and 2016, and are extracted by ArcGIS10.7 (https://

www.resdc.cn/).

3 Results

3.1 The systematicness of the rural regional system

To explore the comprehensive development of the rural regional system elements in the HHHA, the 20 cycles moving average trend line was used to simulate the development level of each element (Fig. 2). And then, in order to observe the comprehensive relationship among the elements of the rural regional system, and consider the expression effect of the figure, all the data was standardized by range standardization. The larger the rural per capita homestead area is, the lower the degree of rural residential land-intensive is. Therefore, it is treated as a reverse index, and the standardized results directly reflect the rural residential land-intensive. That is to say, the higher the standardized value is, the higher the intensive degree of rural residential land is. Because the rural population is a direct reflection of the rural prosperity, we used the arrangement of the rural population density from small to large which would not change the structural relationship between the data, to reflect the overall relationship among the elements of the rural regional system at three-time nodes in HHHA. With the increase of rural population density, only the land-use efficiency of rural residential areas showed an upward trend, and other factors showed a downward trend. Meanwhile, the degree of land intensification of rural residential areas while other factors also showed an opposite trend.

Based on Fig. 2, we can see that the development level of the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land is relatively low. This shows that there are great differences in the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land development among counties in the HHHA, and most counties have poor development level except for some few counties. The development level of the output value of rural primary industry per capita is higher than that of the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land, which is also low. Similarly, the development of individual counties is outstanding, while most counties are at a low level of development. The development level of rural per capita cultivated land area is higher than that of the output value of rural primary industry per capita. Its curve value has a large span, which shows that the spatial differentiation is obvious, that is, there are great differences in different counties. The development level of rural non-agricultural employment rate is higher than that of the rural per capita cultivated land area. Its curve numerical span is relatively small, which shows the spatial differentiation is not as strong as the rural per capita cultivated land area. But most counties are at a relatively high level of development. The rural residential land-intensive degree curve is at the top of all curves. Its numerical span is relatively small compared with the rural per capita cultivated land area. Although it presents a clustering result in space, its spatial differen-

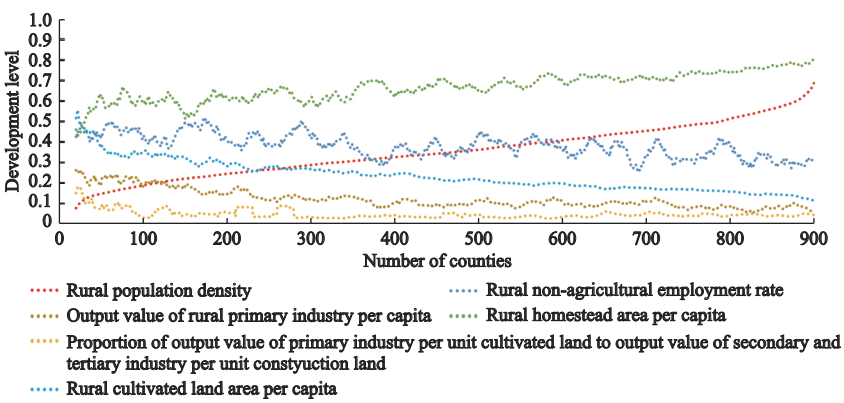

Fig. 2 The moving average 's' curve of rural regional system elements in Huang-Huai-Hai Area (HHHA), China from 2000 to 2015. Rural homestead area per capita is standardized as an inverse index. The larger the standardized value is, the higher the degree of rural residential land-intensive is

tiation is relatively weak compared with the rural per capita cultivated land area. The curve of rural population density has the largest numerical span, which forms an obvious spatial differentiation pattern. There are intersections between the curve and the curve except for the rural per capita homestead area, which indicates that there is a balance between the rural population development and other factors.

3.2 Spatio-temporal evolution of the rural regional system

In 2000, the average development level of the rural regional system in the HHHA was 0.26, and the spatial differentiation was obvious (Fig. 3). A high-value axial belt was formed along the direction of the Beijing-Guangzhou railway, but its spatial continuity was not strong. There are two low-value clusters in the border area of Shandong Province and Hebei Province and the border area of Jiangsu Province and Anhui Province. In 2010, the average level of rural regional system development in the HHHA was 0.31, which showed that the level of rural development had been significantly improved, but its spatial differentiation was relatively weakened. The surrounding areas of Bohai Bay and along the direction of the Beijing-Guangzhou railway formed a high-value development axis, while the development level of other areas was uneven, and there was no obvious spatial pattern. In 2015, the average level of rural regional system development in the HHHA was 0.31, which had little change compared with 2010. Compared with 2010, the high-value belt around Bohai Bay was more prominent, and the high-value axis along the Beijing-Guangzhou railway was more developed, but the spatial pattern of other areas was not obvious.

From 2000 to 2010, the average annual change rate of the rural regional system in the HHHA was 1.80%, showing a state of growth. Only 6 counties have a negative annual change rate of the rural regional system. About 10.00% of the county's rural regional system annual average change rate growth in the (0, 0.8] range. About 32.33% of the county's rural regional system annual growth rate is within the range of (0.8, 1.6], mainly distributed in the western region. About 35.56% of the county's rural regional system annual average change rate growth in the range of (1.6, 2.4], occupying a dominant position. About 11.67% of the county's rural regional system annual average change rate growth in the (2.4, 3.2] range. About 8.33% of the county's rural regional system annual average change rate growth is more than 3.2%. On the whole, the average annual change rate of the rural regional system has a certain spatial differentiation, but its differentiation is relatively weak. A high-value area is formed in the surrounding area of Bohai Bay and Shandong Province, while the value in the western area is relatively low.

From 2010 to 2015, the average annual change rate of the rural regional system in the HHHA was 0.18%, showing a state of growth. About 48.00% of the counties' annual change rate of the rural regional system showed a state of decline, occupying a dominant position. About 12.33% of the county's rural regional system annual growth rate is within the range of (0, 0.8]. About 13.33% of the county's rural regional system annual growth rate is within the range of (0.8, 1.6]. About 8.33% of the county's rural regional system annual growth rate is within the range of (1.6, 2.4]. About

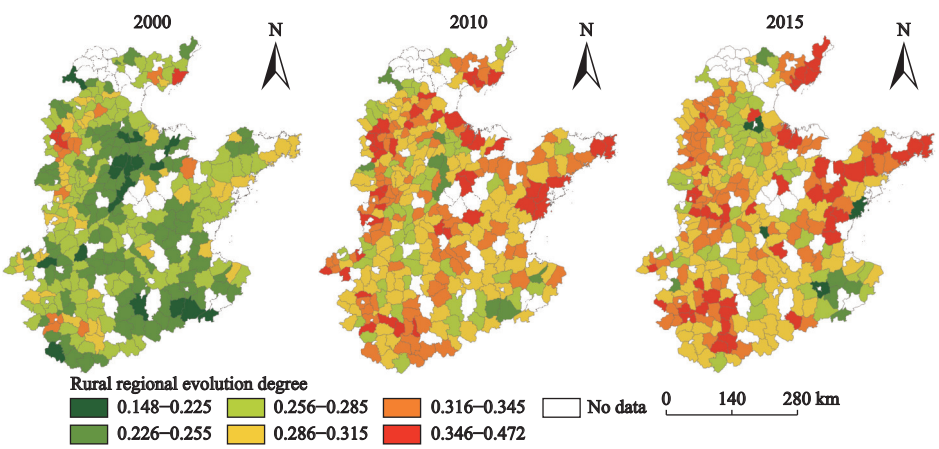

Fig. 3 Spatio-temporal pattern of rural regional system development in Huang-Huai-Hai Area (HHHA), China

5.00% of the county's rural regional system annual growth rate is within the range of (2.4, 3.2]. About 13.00% of the county rural regional system's annual average change rate is more than 3.2%. On the whole, the spatial differentiation of the annual average change rate of the rural regional system is not obvious, and with different values cross-distribution.

From 2000 to 2015, the average annual change rate of the rural regional system in the HHHA was 1.23%, showing a growth state. About 9.00% of the county's rural regional system annual average change rate showed a decreasing state. About 21.33% of the county's rural regional system annual growth rate is within the range of (0, 0.8], which is distributed in clusters in Hebei Province. About 37.33% of the county's rural regional system annual growth rate is in the range of (0.8, 1.6], which is dominant. About 22.00% of the county's rural regional system annual growth rate is in the range of (1.6, 2.4], mainly distributed in Shandong Province. About 6.67% of the county's rural regional system annual growth rate is within the range of (2.4, 3.2]. About 3.67% of the county's rural regional system annual average change rate growth is more than 3.2%. On the whole, the average annual change rate of the rural regional system has a weak spatial differentiation. Shandong Province has formed a high-value area and a low-value axial belt along the direction of the Beijing–Guangzhou railway (Fig. 4).

3.3 Influencing factors of the rural evolution

The gray correlation analysis method is used to analyze the correlation between the evolution of the rural regional system and the driving factors, which reflects the correlation strength between different driving factors and dependent variables in a system. To further screen the key driving factors affecting the evolution of the rural regional system, the average value of the correlation degree between the evolution of the rural regional system and the driving factors are taken as the standard. And then, the index with the gray correlation degree higher than the average value is determined as the screening range of the key driving factors (Table 3 and Table 4). On this basis, the discrimination matrix of the selection range of key driving factors of rural regional system evolution can be obtained. In this table, the influencing factors whose gray correlation degree is greater than or equal to the mean value of correlation degree between rural regional system evolution and each driving factor are recorded as '1', and other indicators are recorded as '0'. Overall, the key driving factors change in different periods.

Combined with the analysis of the key driving factors of the evolution of the rural regional system, the key driving factors of the evolution of the rural regional system and its elements are analyzed by using the geographic detector method. Considering the length of this article, we only explain the effect intensity of the key driving factors of rural regional system evolution, and the key driving factors of other rural elements are shown in Table 5 and Table 6. However, due to the systematicness of rural development, the understanding of the driving mechanism of rural regional system evolution should comprehensively consider the strength of the key driving factors of rural elements, not just the strength of the key driving factors of the rural regional system.

The urbanization rate was only selected as the key

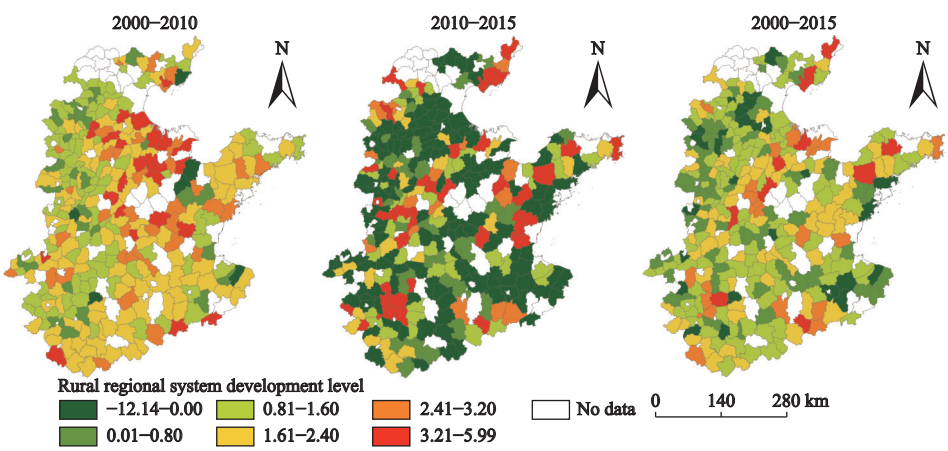

Fig. 4 Spatial pattern of rural regional system evolution in Huang-Huai-Hai Area (HHHA), China

driving factor in the period of 2000–2010 (Table 5). When all factors were considered comprehensively, the urbanization rate had little impact on the rural regional system. GDP per capita was only selected as the key driving factors in the period of 2000–2010, and its effect intensity was the smallest among all the key driving factors (0.0172). The per capita local budget revenue is only selected as the key driving factor in the period of 2000–2010, and its value is 0.0532. The proportion of students in the school was selected as the key driving factor in the two-time periods, but over time, its effect intensity decreased sharply, and it was only

Table 3 Range discriminant matrix of key driving factors of the rural regional system in Huang-Huai-Hai Area (HHHA), China from 2000 to 2010

Rural regional system (2000–2010)	Driving factors (2000)										
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
Evolution of X_1	0	1	0	1	0	1	0	1	0	1	1
Evolution of X_2	0	0	0	0	0	1	0	1	0	1	1
Evolution of X_3	0	1	0	1	0	1	0	1	1	1	1
Evolution of X_4	0	1	0	0	0	1	0	1	1	1	1
Evolution of X_5	0	0	0	0	0	1	0	1	1	1	1
Evolution of X_6	1	0	0	1	0	1	1	1	0	1	1
Evolution of rural regional system	1	1	0	1	0	1	0	1	0	0	0

Notes: Meaning of X_1–X_6 see Table 1, meaning of Z_1–Z_{11} see Table 2

Table 4 Range discriminant matrix of key driving factors of the rural regional system in Huang-Huai-Hai Area (HHHA), China from 2010 to 2015

Rural regional system (2010–2015)	Driving factors (2010)										
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
Evolution of X_1	0	1	0	1	0	1	0	1	0	1	1
Evolution of X_2	0	0	0	0	0	1	0	1	0	1	1
Evolution of X_3	0	1	0	1	0	1	0	1	1	1	1
Evolution of X_4	0	1	0	0	0	1	0	1	1	1	1
Evolution of X_5	0	0	0	0	0	1	0	1	1	1	1
Evolution of X_6	1	0	0	1	0	1	1	1	0	1	1
Evolution of rural regional system	1	1	0	1	0	1	0	1	0	0	0

Notes: Meaning of X_1–X_6 see Table 1, meaning of Z_1–Z_{11} see Table 2

Table 5 The intensity of the key factors influencing the evolution of the rural regional system in Huang-Huai-Hai Area (HHHA) from 2000 to 2010

Rural regional system (2000–2010)	*q*-statistics (2000)										
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
Evolution of X_1		0.0379		0.0704		0.2372		0.0508		0.0332	0.0471
Evolution of X_2						0.0518		0.0713		0.0260	0.0873
Evolution of X_3		0.0253		0.0562		0.0192		0.0351	0.0710	0.1434	0.2540
Evolution of X_4		0.0132				0.0170			0.0635	0.1364	0.2377
Evolution of X_5						0.6105		0.0516	0.0440	0.0188	0.0234
Evolution of X_6	0.0406	0.0448		0.0510		0.0236	0.023	0.0425			
Evolution of rural regional system	0.0390	0.0172		0.0532		0.1444		0.0305			

Notes: Meaning of X_1–X_6 see Table1, meaning of Z_1–Z_{11} see Table2

Table 6 The intensity of the key factors influencing the evolution of the rural regional system in Huang-Huai-Hai Area (HHHA), China from 2010 to 2015

Rural regional system (2010–2015)	*q*-statistics (2010)										
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
Evolution of X_1	0.0732	0.1384		0.1039	0.0724		0.0605	0.0693			0.1748
Evolution of X_2	0.1019					0.0169	0.0209	0.0386	0.0460	0.0231	0.0254
Evolution of X_3	0.0791	0.1616		0.1132	0.0925		0.0541	0.0823			0.0426
Evolution of X_4	0.0835	0.1696	0.1154	0.1226	0.1056		0.0526	0.0804			0.0441
Evolution of X_5	0.1068	0.1208				0.0713	0.0586	0.0616	0.0166	0.0257	0.0260
Evolution of X_6	0.0484	0.0360		0.0390		0.0436	0.0225	0.0110			
Evolution of rural regional system						0.0189	0.0365	0.0298	0.0438	0.0194	0.0664

Notes: Meaning of X_1–X_6 see Table1, meaning of Z_1–Z_{11} see Table2

0.0189 after 2010. After 2010, the effect of the number of adoptive beds of social welfare per capita in the county decreased, and the effect intensity was the largest from 2000 to 2010 (0.0878). The number of medical and health beds per capita in the county was selected as the key driving factor in the two-time periods, but its effect intensity was low (no more than 0.0513). The total power of average agricultural machinery was not selected as the key driving factor in the period of 2000–2010 and reached the maximum value (0.0766) from 2000 to 2010. After 2010, its effect intensity decreased. The shortest distance to the city was not selected as the key driving factor in 2000–2010, and the effect intensity was small in the other two time periods (no more than 0.0200). The effect intensity of road network density in 2010–2015 is 0.0664 (Table 6).

3.4 The evolution mechanism of rural regional system

3.4.1 Fluctuation and spiral upward development of rural development

The elements of the rural regional system are not independent of each other, and there is a certain correlation between them. From the 20 cycles moving average 's' curve of each factor in the rural regional system, it can be seen that with the increase of rural population density in the county, only the land-use efficiency of rural residential areas is on the rise, and other factors are on the decline. The increase of rural population density can improve the utilization rate of rural residential land, that is, the return of rural population not only increases the vitality of the countryside but also avoids the waste of rural homestead. With the increase of farmers' going out to work, the rural non-agricultural employment rate increases, and the increase of farmers' non-agricultural part-time employment causes the loss of the rural population. Therefore, reducing the large-scale long-distance migration of farmers and Realizing Farmers' nearby employment can effectively solve the problems of rural vitality decline and farmers' income. With the improvement of primary production technology, the output value of primary production is constantly increasing, but the per capita output value of rural primary production in counties with high population density is relatively low, and the benefit of rural primary production still needs to be further improved. With the benefit of the secondary and tertiary industries getting higher and higher compared with the primary industry, the reduction of the relative economic benefit of the primary industry makes more farmers give up agriculture and join in other industries, which makes the rural population density decline. HHHA is mainly plain. With the development of urbanization, rural cultivated land is in a relatively stable state. Therefore, population and resources are often coerced each other, that is to say, too much population will cause pressure on resources, and resources in turn force people to adapt to the environment through non-agricultural and part-time business. To achieve sustainable development, we need to achieve balanced development between population and resources.

The relationship between the elements of the rural regional system makes the rural regional problems often occur simultaneously. For example, the rapid loss of rural population not only causes the problems of rural housing vacancy and land abandonment but also affects

the vitality of rural economic development. It is in the evolution of the rural regional system that the problem of rural region arises, which is dominated by the unbalanced evolution of a certain factor and formed by the joint action of multiple factors. The 'rise and fall' fluctuating evolution characteristics of the elements of the rural regional system result in the fluctuating evolution of the rural regional system. However, in the study period, the whole system is on the rise, that is, the evolution of the rural regional system is spiraling. In the study period, the average annual evolution rate of the rural regional system was positive, but after 2010, there had been a significant decline, and the development of the rural regional system had stagnated, which was due to the great changes in the evolution of various elements. During the research period, four elements of the rural regional system had been found to have changed. Although the other two elements had not changed their direction of evolution, their evolution rate had changed greatly, which promoted the spiral upward development of the rural regional system in the 'rise and fall' succession. However, the development of the rural regional systemwas facing resistance.

3.4.2 The driving mechanism of rural population-land-industry evolution

Through the analysis, it can be found that the mechanism of driving factors has changed in different periods (Fig. 5). Generally speaking, the development of county urbanization has become more and more important with time. However, the role of cities in rural evolution is not obvious. It can be seen that with the gradual improvement of China's urban system and the development of counties, the driving role of county towns in rural areas began to strengthen. However, with the end of the rapid expansion of some cities, the rapid impact of cities on rural areas has gradually come to an end. To a certain extent, the development of county urbanization has increased the gap between rural and urban land average output value, and led to the decline of rural per capita output development level and the low efficiency of rural homestead land use, but the positive effect on the evolution of other factors began to highlight. The development of the county economy not only reduces the efficiency of rural homestead land use but also has a positive effect on the evolution of other factors. The development of the county economy has effectively stabilized the rural population and reduced the gap between rural and urban land output value to a certain extent, which plays an important role in improving the relationship between urban and rural areas within the county. The improvement of public service can improve the overall development environment of the county, to promote the upward development of the rural regional system. The development of agricultural mechanization has effectively liberated the rural labor force and improved the production efficiency of the primary industry so that people can invest more in the non-agricultural industry, driving the growth of rural residents' income. In the period of rapid urban expansion, the rural areas around the city often get strong development radiation, which has a dramatic impact on the development of the rural regional system. With the overall development of the region, the development of the rural regional system is driven by the development of the counties in the areas far away from the city, which makes the influence of the factors from the city begin to weaken. Transportation is a prerequisite for the development of a region. The development of transportation enhances the local external connectivity and benefits the development of rural areas.

In the evolution of the rural regional system, the urbanization and rural development of county areas promote each other. Therefore, the urban-rural integration can be realized through the double wheel drive of 'new urbanization and rural revitalization'. The development of the county economy provides economic support for the development of the whole region. This is to promote the development of the rural regional system through the improvement of the overall regional economic environment, which is the embodiment of the theory of balanced development. Public service provides the welfare sharing foundation for urban and rural areas and lays the foundation for the realization of urban and rural equivalent development, which effectively guides the evolution direction of the rural regional system. Cities have both agglomeration effect and diffusion effect. The areas close to cities, especially important cities, are often driven by the radiation of cities. However, as time goes on, the influence of cities on the rural regional system decreases, and the development of counties begins to play an important role. Transportation enhances the connection between economy and resources, makes resources flow more efficiently, and provides external connection support for the evolution of the rural regional system. The development of agricultural mechaniza-

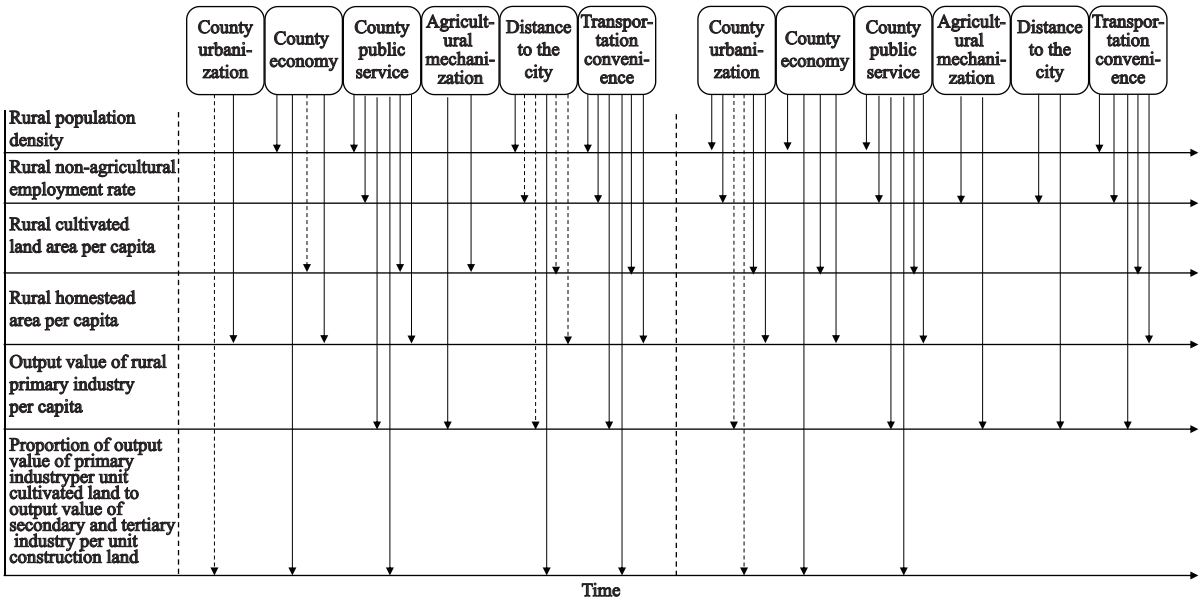

Fig. 5 Evolution of key driving factors of rural regional system evolution

tion can effectively improve the production efficiency of primary industry, which is the core industry in rural areas, and thus promote the transformation of rural production and lifestyle (Fig. 6).

The policies of China and governments at all levels on rural areas will also play a vital role in rural development. However, due to the difficult measurement and uncertainty of policy impact, this study does not quantitatively measure the policy impact. Since 2000, under the background of rural reform, China's rural development has experienced major strategic adjustments, such as agricultural structure adjustment (1999–2003), agricultural and rural construction (2004–2012), beautiful rural construction (2012–2017), rural revitalization (2018–), which are rooted in the understanding of rural problems in different periods to effectively solve rural development problems. The formulation and implementation of these major policies constantly regulate and control the rural development through human intervention, so as to make the rural development in a sustainable direction. This is also the logic of the continuous spiral improvement of rural development level.

3.4.3 Evolution mechanism of rural regional system

The rural regional system can be characterized by different indicator systems, which is systematic. The indicators do not exist in isolation but often interact with each other, thus promoting the continuous development of the whole system. Besides, due to the geographical differentiation, the rural regional system has formed a

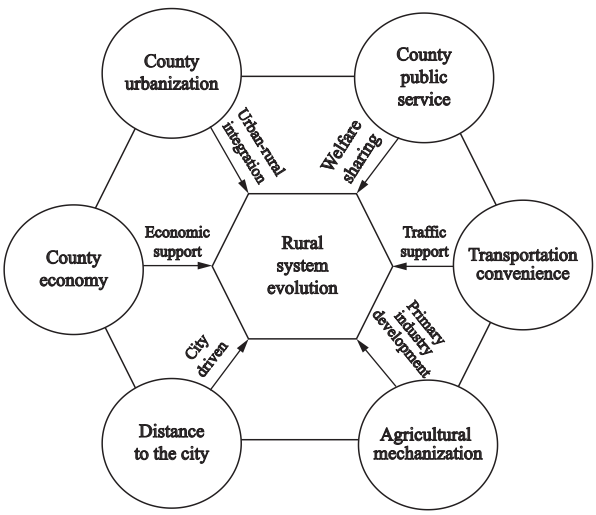

Fig. 6 Driving mechanism of rural regional system evolution

specific spatial pattern in a certain region. Over time, the evolution of the rural elements will appear differentiation, that is, some elements grow rapidly while others decline rapidly, leading to the maladjusted development of the whole system. Superimposed on the systematic characteristics of the rural regional system, the interaction between different elements, aggravating the maladjusted development of the whole system, leading to the decline of the rural regional system. In extreme cases, such as the rapid loss of rural population and rural homestead land has not changed, it will lead to 'serious waste of rural construction land' and other rural diseases. When the rural regional system is in a state of maladjusted development, on the one hand, the system

will adjust itself to make the system stable again, but the process is often slow. On the other hand, the system can be adjusted artificially to make the system recover to a stable state quickly. To carry out man-made regulations, it is necessary to diagnose the evolution of the rural regional system and provide a basis for regulation. The evolution process of the rural regional system will be affected by many factors, such as urbanization, county economic development, surrounding cities, and so on. These factors will accelerate or slow down the evolution process of the rural regional system, and form the driving factors of rural regional system evolution. The whole process of rural regional system evolution can be summarized as follows: under the action of internal factors and driving factors, the state of the rural regional system will evolve. In this process, we need to analyze the problems existing in its evolution, to carry out human intervention and regulation on its evolutionary direction, so that the system can recover to a stable state faster and further growing (Fig. 7).

3.4.4 Classification of rural evolution types

In this study, six factors are selected to reflect the development of the rural regional system. The evolution of each element presents different characteristics. To explore the characteristics of its overall evolution type, the counties with declining elements are recorded as '–1', while the counties with increasing elements are recorded as '1', so that the growth type of each element can be recorded as {–1, 1} two types. If all the feature types are superimposed, a set of integer data sets between [–6, 6] can be obtained theoretically. When the value is '– 6', it means that the evolution of all elements are decreased, while when the value is '6', it means that the evolution of all elements is increased. The larger the index of 'per capita homestead area' is, the less intensive use of land resources is. Therefore, reverse treatment should be done to it, that is, if the evolution rate is positive, it is recorded as '–1', and if the evolution rate is negative, it is recorded as '1'. Through calculation, the data set of superimposed evolution types of rural regional system elements from 2000 to 2015 is {– 4, – 2, 0, 2, 4 }. For the whole rural regional system, upward development is its goal. Therefore, the larger the value is, the greater the growth of the rural regional system is. Based on this, the county with {– 4, – 2} value is classified as recession type, the county with 0 value is classified as balanced type, and the county with {2, 4} value is classified as growth type (Fig. 8).

Growth-oriented counties are mainly distributed in the central and western regions, a total of 95 counties. Among them, the rural population density and rural homestead land-use efficiency are in a state of decline, while other factors are in a state of growth in 51 counties, which occupy the dominant position of this type. Among the 51 counties, there are 41 counties with increasing rural population density, rural non-agricultural employment rate, and rural per capita output value. Furthermore, in these 41 counties, the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per

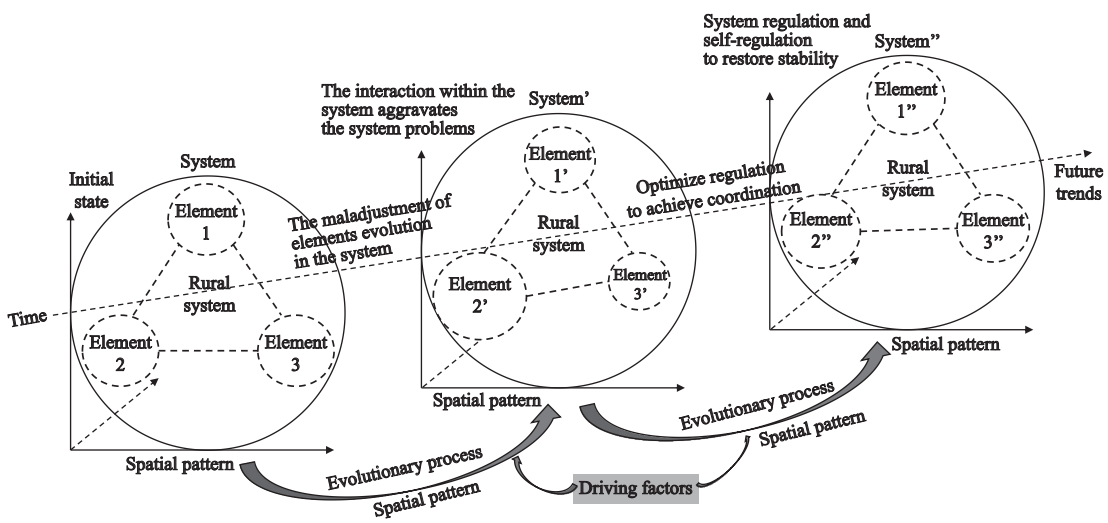

Fig. 7 Evolution mechanism of rural regional system. System, system', system" refer to the same rural regional system respectively, which presents different states at different time nodes

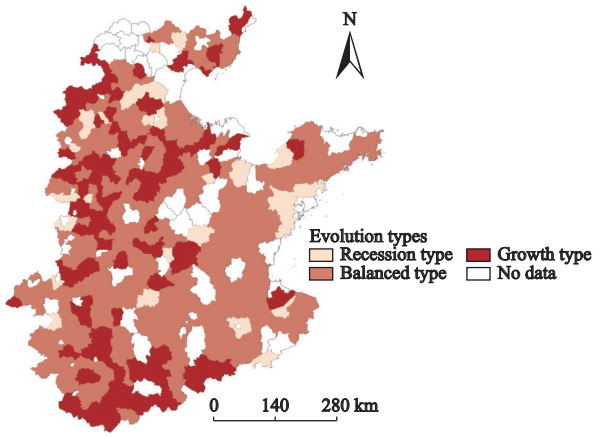

Fig. 8 Classification of rural regional system evolution types in Huang-Huai-Hai Area (HHHA), China

unit construction land and the rural per capita cultivated land area are in a state of decline, while the other factors are in a state of growth, a total of 22 counties. There are 177 balanced counties, which are the main types of counties in the area. Among them, there are 146 counties in which the rural population density, the proportion of output value of primary industry per unit cultivated land to the output value of secondary and tertiary industry per unit construction land, and the land-use efficiency of the rural homestead are declining, while other factors are increasing, occupying the dominant position of this type. There are 28 declining counties in total, which are mainly distributed into the eastern region. Among them, there are 20 counties whose output value of rural primary industry per capita and rural per capita cultivated area are increasing, while other factors are declining, which occupy the dominant position of this type.

4 Conclusion and Suggetions

The development of rural areas is facing various problems, so it is urgent to understand the evolution mechanism of the rural regional system from a systematic perspective. Based on the systematicness of the rural regional system, this paper analyzed the spatio-temporal pattern and driving mechanism of rural regional system evolution, and further summarized and refines the evolution mechanism of the rural regional system. This study can provide a reference for understanding the process of rural prosperity and decline and can guide rural revitalization and rural sustainable development. The main results are as follows.

First, the rural regional problems are often led by one factor and produced under the joint action of multiple factors. At the same time, the evolution of population-land-industry in rural areas shows a spiral upward development. However, the development of the rural regional system is facing resistance.

Second, the evolution process of rural population-land-industry will be affected by county urbanization, county economy, county public service, agricultural mechanization, surrounding cities, and transportation convenience. With the gradual improvement of China's urban system and the development of counties, the driving role of county towns in rural areas began to strengthen. However, with the end of the rapid expansion of some cities, the rapid impact of cities on rural areas has gradually come to an end.

Third, based on the evolution of the elements, the evolution types of rural regional systems can be divided into recession type, equilibrium type, and growth type. The classification method can reflect the problems existing in the evolution of rural factors.

Fourth, it is urgent to optimize the structure of the primary industry and renovate hollow villages at present. Besides, it is also necessary to strengthen the protection of cultivated land and actively promote the overall economic development of the county.

There are problems in the growth type counties, such as the decline of the rural population, the rapid expansion of rural homestead area, the widening of the gap between rural and urban land output value, and the decline of per capita cultivated land area. The problems are different in different counties, but these problems are relatively more than others in this area. Therefore, for the growth-type counties, we need to optimize from three aspects: first, we should protect the cultivated land resources and prevent them from being occupied by construction; second, we should effectively promote the renovation of hollow villages, demolish the houses that have not lived for a long time and turn them into cultivated land; third, optimize the structure of the first production and improve production efficiency. Because the change of the population is also driven by other factors, it is impossible to take single population control as an optimization strategy. The balanced counties mainly have the problems of rural population recession, the widening of the gap between rural and urban land output value, and the low efficiency of rural homestead land use. It needs to be optimized from two aspects: one is to

improve the production efficiency, the other is to renovate the hollow village. The declining counties mainly have the problems of rural population recession, rural non-agricultural employment rate decline, the widening of the gap between rural and urban land output value, and low rural homestead land-use efficiency. The proportion of such counties is relatively small, which can be optimized from the following three aspects: first, to develop the county economy and improve the county employment opportunities; second, to optimize the structure of the primary industry; third, to carry out the optimization hollowed village renovation. Generally speaking, the low efficiency of primary production and the hollowing of villages are the common problems of these several types. Therefore, it is urgent to optimize the structure of the primary industry and renovate hollow villages. Besides, it is necessary to strengthen the protection of cultivated land and actively promote the overall economic development of the county.

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