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Calculation and Driving Mechanism of Spatio - Temporal Evolution of Rural Occupational and Residential Functional Efficiency in Jilin Province Based on Geographic Detection Modeling

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ABSTRACT

Rural population loss is a common phenomenon in northeast China, even in the whole country and all over the world, has significantly hindered economic and social development in rural areas, leading to a weakening of growth momentum and even stagnation. In view of this, this paper focuses on Jilin Province, a typical region, and uses key data such as rural resident population, rural employed population, and job supply in the region from 2008 to 2021. Through the comprehensive application of spatial autocorrelation analysis methods and the geographical detector model, it deeply analyzes the spatio-temporal evolution patterns of the rural occupational and residential function-efficiency at the county scale in Jilin Province, the trade-off and synergy relationships, and the driving mechanisms behind them. The results show that: the synergy level of the rural occupational and residential function-efficiency index in Jilin Province has gradually increased over time; the index shows a steady upward trend and spatial clustering characteristics; the index is influenced by a variety of driving factors, and the mechanisms of these factors vary. These findings will help the government formulate sustainable rural development policies and provide a useful reference for promoting comprehensive rural revitalization and development.

Keywords: Jilin Province, population loss, occupational and residential functions, occupational and residential efficiency; driving mechanisms

1. Introduction

Urbanization is the process of transforming agricultural population and agricultural land to non-agricultural population and urban land, which is the necessary path of modernization and an important way to solve the three rural problems [1]. From the point of view of China's urbanization rate, the

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development of China's urbanization is in the form of an S-curve, and it is changing from rapid development to smooth development and from speed-based development to quality-based development [2-4]. With the implementation of the new urbanization strategy, people-oriented and human urbanization has attracted much attention, which emphasizes the construction of new spaces for the rural masses, especially new employment spaces and residential spaces, and how to reasonably resettle the rural migrant population in terms of employment and residence has become an arduous task [5-7].

Since the reform and opening up, with the rapid development of China's urbanization, there has been a large influx of rural surplus labor force to cities, and at the same time, the rural employed population is generally facing social problems such as family disintegration, pendulum commuting, and left-behind families [8-9]. In the future, China still has the problem of “three hundred million people” to face, which all involves the residence and employment of the rural employed population [10]. At the same time, one of the priorities of the new urbanization and rural revitalization strategy is to coordinate the relationship between the residence and employment of the rural working population, which puts forward new requirements for the work-life balance [11-12]. However, in the process of real urbanization, it is difficult for the rural transfer population to truly realize citizenship, and there still exists employment inequality such as different pay for the same work, different time for the same work, and different rights for the same work, as well as residential problems such as chaotic living environment, poor quality of living, and insecure housing [13-15]. In addition, the current domestic research on rural urbanization mainly focuses on the problems of rural urbanization, the mode of rural urbanization, the dynamics of rural urbanization and the influencing factors, etc., and there is a relative lack of research based on the work-life perspective [16-17]. Therefore, the issue of work-life balance of the rural employed population has become an insurmountable issue of the times.

Due to economic development constraints and geographical location, most counties in Northeast China have low levels of resource and environmental carrying capacity, and their socioeconomic development has stagnated. This has led to a significant number of rural residents working outside their hometowns for extended periods, with a noticeable trend of rural populations migrating to the developed coastal cities in Northeast China. This exacerbates the issue of population loss in the region, resulting in stagnation or even economic regression at the county level. Therefore, this study uses Jilin Province, which has a severe population loss in Northeast China, as a case example to analyze the rural occupational and residential function-efficiency index levels and their influencing factors in 2008, 2015, and 2021. The objectives of this study are as follows: (1) to analyze the connotation of the rural occupational and residential function-efficiency index at the county level; (2) to elaborate on the spatiotemporal characteristics and trade-off-synergy development of the index in Jilin Province, identifying the issues faced in the development of the index; (3) to explore the driving forces and dominant factors of regional differences in the index, providing a scientific basis for promoting sustainable rural development.

2. Theoretical framework

2.1. The connotation of the rural occupational and residential function-efficiency index and its spatiotemporal evolution and tradeoffs theory

Employment and housing are common topics in studying the living standards of populations across different regions. In some studies, the concept of "jobs-housing balance" suggests that an ideal distribution of urban work and residential locatioSSns should be balanced and close, enabling residents to work and live locally. The concept of the Rural Occupational and Residential Function-Efficiency Index is similar to the "jobs-housing balance" as both aim to minimize commuting costs, improve the convenience of employment and housing for residents, facilitate government coordination, reduce traffic pressure, protect the environment, increase housing and employment rates, and promote sustainable socio-economic development. However, most current research only provides a basic analysis of the

balance between employment and housing without delving deeper. Therefore, this paper will conduct an in-depth study of the Rural Occupational and Residential Function-Efficiency Index, focusing on its spatiotemporal evolution patterns, trade-off and synergy relationships, and the driving mechanisms behind these aspects.

In analyzing the rural occupational and residential function-efficiency index at the county level, the overall balance between residential and employment functions, and the quality of their coordination, should be considered. Attracting a large number of rural residents to reside and seek employment within the county is not only beneficial for alleviating the economic imbalance between urban and rural areas but also effectively promotes the diversification and growth of the county's economy. In this process, county regions can provide various necessary employment opportunities, thus creating more occupational options for local farmers. This approach ensures a more reasonable allocation of labor resources while also ensuring that farmers earn higher incomes locally. Drawing on the concept of occupational and residential balance in cities and related research on the rural occupational and residential function-efficiency index, this paper defines the county-level rural occupational and residential function-efficiency index as the ability of rural residents to live and work in the same region, with both functions relatively balanced. Based on this definition, this paper comprehensively measures the function-coordination index of rural occupational and residential balance using a variety of population, employment, and economic data. A targeted study of trade-offs and synergies is conducted, and driving indicators are selected from natural, social, economic, and internal system factors to measure the factors affecting rural occupational and residential balance. The interactive mechanisms between different types of factors are analyzed, and relevant suggestions are proposed. The specific theoretical framework is shown in Figure 1.

The spatiotemporal evolution of the rural occupational and residential function-efficiency index reflects the changes over time and spatial differences in the efficiency of rural occupational and residential functions. Under different spatiotemporal conditions, the efficiency of rural areas' occupational and residential functions exhibits distinct characteristics. With the development of the social economy, especially the improvement of infrastructure and public services, the efficiency of occupational and residential functions in some rural areas may be enhanced. In economically developed areas, where public services are more comprehensive, infrastructure is better, and employment opportunities are more abundant, the coordination of occupational and residential functions is higher, and the efficiency level is also higher. In contrast, in economically weaker regions, especially those with scarce resources or underdeveloped infrastructure, the coordination of occupational and residential functions is poorer, and the efficiency level is lower. This gap reflects the regional disparities in the spatiotemporal evolution. By incorporating tradeoffs theory, the spatiotemporal evolution of the rural occupational and residential function-efficiency index can be further explained. When resources are limited, there is often a competitive relationship between occupational and residential functions. For example, in some rural areas with slower economic development, the government tends to prioritize resource allocation to enhance employment opportunities or improve infrastructure, which may delay improvements in housing conditions, and vice versa. Therefore, the application of trade-off theory here reveals how to achieve the optimal balance between occupational and residential functions in the context of limited resource allocation, thus promoting the improvement of rural occupational and residential function efficiency.

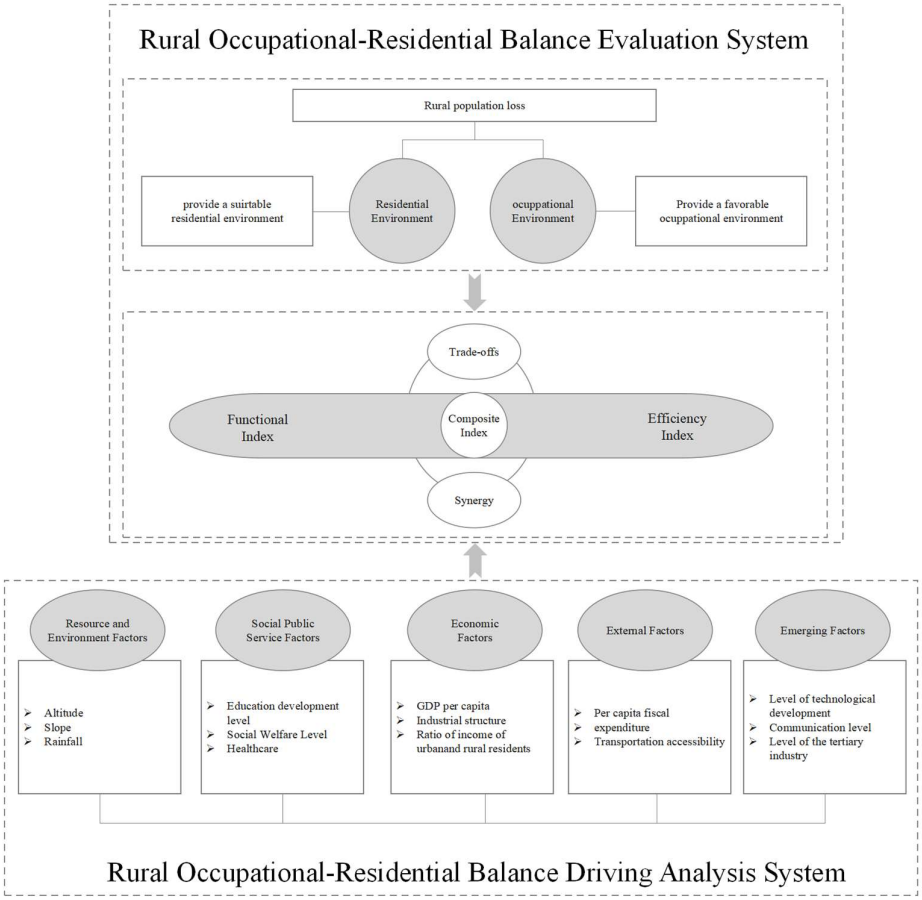

Fig. 1. Theoretical framework of the Rural Occupational and Residential Functional-Efficiency Index

2.2. The driving mechanisms of the rural occupational and residential function-efficiency index

The formation of the rural occupational and residential function-efficiency Index is driven by multiple factors, which not only determine the fundamental conditions of rural occupational and residential functions but also profoundly influence the regional disparities and spatiotemporal evolution of its efficiency levels. According to systems theory and multi-dimensional coordination theory, the interaction and coordination between various system elements play a crucial role in understanding the complex relationship between rural occupational and residential functions. The employment opportunities and residential conditions in rural areas do not exist in isolation but are closely related to various factors, including the natural environment, social public services, and economic development. The coordinated collaboration of these factors facilitates an efficient balance between rural occupational and residential functions.

Resource and environmental factors are one of the key elements influencing the efficiency of rural occupational and residential functions. The natural environment directly affects agricultural production methods and land use patterns, which in turn influence the spatial distribution of employment and residential patterns in rural areas. For example, Clarke's study shows that natural factors such as climate, topography, and water resources determine the agricultural production methods in rural areas, thereby affecting the spatial distribution of employment opportunities. Social public service factors, especially the provision of education and healthcare services, are essential for enhancing the attractiveness of rural areas for residency and employment opportunities. The improvement of public services can directly enhance living conditions in rural areas and promote the coordination of occupational and residential functions. In particular, investments in education and healthcare contribute to

improving the quality of the rural labor force, thereby promoting economic development and the creation of employment opportunities. Economic Level significantly impacts the efficiency of rural occupational and residential functions. The economic foundation of rural areas determines both the quantity and quality of employment opportunities, further influencing the coordination of occupational and residential functions. Areas with strong economic foundations can effectively improve the coordination between rural occupational and residential functions. In contrast, regions with weak economic foundations face issues such as insufficient employment opportunities and a lack of coordination between occupational and residential functions. External Factors, particularly government fiscal expenditure and infrastructure development, is another key factor in driving the efficient coordination of rural occupational and residential functions. Government investments in transportation infrastructure, housing construction, and public services significantly improve the employment and residential conditions in rural areas, thereby promoting the comprehensive development of rural economies and societies. Emerging Factors, particularly the widespread use of information and internet technologies, are changing traditional employment models and residential patterns. Research has found that with the rise of remote work and e-commerce, the application of information technology in rural areas not only improves the distribution of employment opportunities but also enhances the living conditions of rural residents. The widespread adoption of emerging technologies facilitates the diversification of the employment market and the mobility of labor between urban and rural areas, further promoting the efficient coordination of rural occupational and residential functions.

Therefore, the formation mechanism of the rural occupational and residential function-efficiency index is the result of the combined influence of multiple factors. The interaction and coordination of natural environmental factors, social public services, economic development, external support, and emerging technologies collectively determine the efficiency levels of rural occupational and residential functions. The optimization and mutual collaboration of these factors drive sustainable development and improve the quality of life in rural areas.

3. Study Area and Research Methods

3.1. Study Area

Jilin Province is located in the central part of Northeast China and is one of nine border provinces in the country. It serves as an important window for the "Belt and Road" initiative's northern opening. Jilin Province's geographical features are distinct, with terrain gradually decreasing from southeast to northwest. Therefore, the province is typically divided into three regions based on topographical differences: the southeastern mountainous area, the central hilly region, and the northwestern plain (Figure 2). Jilin Province covers a total area of 187,400 square kilometers and consists of 60 counties. These counties include large cities, villages, mountainous areas, and ethnic minority regions. Due to differences in terrain, economic levels, and cultural diversity, there are significant regional disparities in the rural residential and employment spaces within Jilin Province.

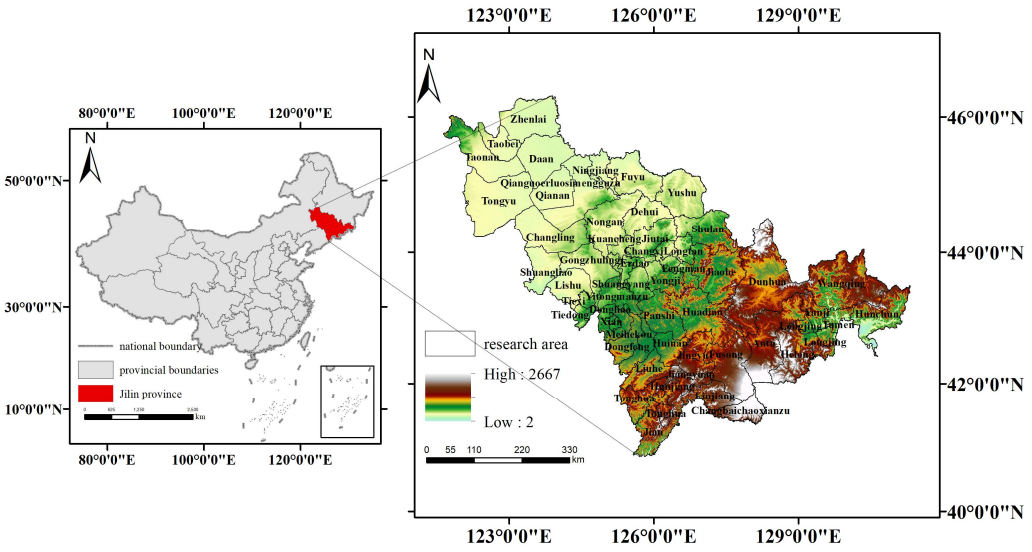

Fig. 2. Location Map of Jilin Province

3.2. Data Source

This study uses Jilin Province's 60 counties as the research units, with the study period being 2008, 2015, and 2021. In 2008, Jilin Province began its county-level reform pilot project, implementing various measures to support rural development, resulting in significant growth in rural construction. By 2015, the provincial government had fully implemented the targeted poverty alleviation strategy, leading to noticeable differences in the urban-rural growth gap. After the 19th National Congress of the Communist Party of China proposed the Rural Revitalization Strategy, 2021 marked a key point in achieving the country's poverty alleviation goals. The rural occupational and residential coordination features in Jilin Province are better reflected at these three time points. The population data and socio-economic development data used in this paper are derived from the 2008, 2015, and 2021 editions of the "China County Statistical Yearbook"(https://www.stats.gov.cn/zs/tjwh/tjkw/tjzl/202302/t20230215_1908004.html) and "Jilin Statistical Yearbook,"(http://tjj.jl.gov.cn/tjsj/tjnj/) and data published on the official websites of the county governments in Jilin Province. DEM data comes from the Geospatial Data Cloud, and the average slope and elevation of each county were processed using ArcGIS. Ecological environment data were obtained from county environmental and water resources statistical bulletins. Missing personal data were interpolated with data from similar years.

3.3. Rural Occupational and Residential Function-Efficiency Index

The study of the occupational and residential function-efficiency index typically measures the overall degree of "employment-residential" balance in a region, and the degree of spatial matching between residential and employment areas is used to verify the status of this balance. This research adopts methods for measuring the rural occupational and residential function-efficiency index, drawing from previous research. Using a comprehensive measurement model, the study assesses function balance and efficiency. On this basis, an entropy weight method is applied to quantitatively measure the rural occupational and residential function-efficiency index, allowing for the differentiation of index characteristics and preventing the misjudgment of the rural occupational and residential function-efficiency index due to the sole consideration of residential-employment function balance.

The model is as follows:

$$S_{nk} = W_{k1} PJ_{ij} + W_{k2} OI_{ij} (n = 1,2,3 \ldots f; k = 1,2,3 \ldots g) \quad (1)$$

In formula (1), S_{nk} represents the rural occupational and residential function-efficiency index for a given research area. The larger the value, the better the coordination between residential and employment functions. W_k represent the weight values of indicators. PJ_{ij} represents the rural employment-population ratio for the research unit in year t, and OI_{ij} represents the rural residential-population ratio. The values of PJ_{ij} and OI_{ij} indicate whether a county's rural employment and residential functions are balanced. If $PJ_{ij} > 1$, the employment function is stronger than the residential function; if $PJ_{ij} < 1$, the employment function is weaker. When PJ_{ij} is close to 1, the residential and employment functions are relatively balanced.

$$PJ_{ij} = 2 - \left|1 - FI_{ij}\right| \tag{2}$$

$$FI_{ij} = \frac{E_{ij} / E_i}{R_{ij} / R_i} \tag{3}$$

In equation (3), E_{ij} represents the rural employed population of county j in year i,and E_i represents the rural employed population of Jilin Province in year i. R_{ij} represents the rural permanent resident population of county j in year i, and R_i represents the rural permanent resident population of Jilin Province in year i.

The ratio of rural employed population to rural permanent resident population reflects the balance between the “residential and employment” functions of the rural population in a county. If the ratio is greater than 1, it indicates that the rural employment function in that county is stronger than its residential function. If the ratio is less than 1, it suggests that the rural employment function is weaker than its residential function. When the ratio approaches 1, it means that the residential and employment functions of rural residents in the county are relatively balanced.

In order to better assess the degree of the rural occupational and residential functional-efficiency index from both the perspectives of functional balance and synergy efficiency, PJ_{ij} is introduced, based on previous research, to achieve this goal.

$$OI_{ij} = \frac{J_{ij}}{G_{ij}} \tag{4}$$

Equation (4) uses Cervero's "occupationals-residential ratio" to measure the degree of employment self-sufficiency in a given area. J_{ij} represents the number of non-agricultural employment positions provided in region j in year i (the number of rural residents engaged in the secondary and tertiary industries). G_{ij} represents the number of working-age rural residents living in region j in year i.

The ratio of these two variables reflects the number of non-agricultural employment opportunities provided in the study area relative to the number of working-age rural residents. This ratio represents the level of self-sufficiency in non-agricultural employment in the county and also reflects the quality of non-agricultural employment available to the rural population in the area.

3.4. Analysis of the Trade-Offs and Synergies of the Rural Occupational and Residential Functional-Efficiency Index

The trade-off and synergy have distinct meanings. The trade-off represents a negative correlation between the rural occupational and residential function index and the efficiency index within the same period, where the two move in opposite directions—when one rises, the other falls. In contrast, synergy reflects a positive correlation between the occupational and residential function index and the efficiency index, where both increase or decrease simultaneously. The model is as follows:

$$RHTD = \frac{WP_a - WP_b}{WO_a - WO_b} \tag{5}$$

In equation (5), WP_a and WP_b represent the weighted rural occupational function indices at times a and b, respectively, while WO_a and WO_b represent the weighted rural efficiency indices at times a and b, respectively. $RHTD$ represents the Trade-off and Synergy Degree of the Rural Occupational and Residential Function-Efficiency Index. When $RHTD$ is positive, it indicates that there is a synergy between the function index and the efficiency index, meaning both follow the same trend. When $RHTD$ is negative, it indicates a trade-off between the function index and the efficiency index, meaning they exhibit opposite trends. The absolute value of $RHTD$ reflects the degree of synergy or trade-off.

The synergy and trade-off levels are classified into eight categories: -12 to -9 (Significant Trade-Off), -9 to -6 (High-Level Trade-Off), -6 to -3 (Mid-Level Trade-Off), -3 to 0 (Low-Level Trade-Off), 0 to 3 (Low-Level Synergy), 3 to 6 (Mid-Level Synergy), 6 to 9 (High-Level Synergy), and 9 to 12 (Significant Synergy).

3.5. Spatial and temporal study of rural occupational and residential function-efficiency

The spatial-temporal characteristics of the rural occupational and residential functional-efficiency index were analyzed using the spatial autocorrelation method. Spatial autocorrelation includes both global spatial autocorrelation and local spatial autocorrelation, which measure the degree of interdependence between attributes at a given location and can express the correlation that arises from spatial proximity. Equation (6) applies the global Moran's I index to assess this correlation.

$$I = \left[\sum_{i=1}^{n}\sum_{j\neq i}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})\right] / (s^2 \cdot \sum_{i=1}^{n}\sum_{j\neq i}^{n} W_{ij}) \tag{6}$$

In equation (6), I represents the global Moran's I index, while x_i and x_j denote the observed values of elements I and j, W_{ij} respectively. s^2 is the spatial weight, is the variance, and $\bar{x}$ is the mean of the observed values. When $I>0$, the observed values exhibit a significant positive spatial correlation, and the larger the value, the stronger the clustering. Conversely, when $I<0$, it indicates a negative spatial correlation. If $I=0$, there is no spatial correlation. Additionally, hotspot analysis tools are used to explore local areas within each region and national cluster that show high or low residential-employment synergy. The Local Indicators of Spatial Association (LISA) cluster maps are employed to reveal the primary cluster units.

$$G_i^* = (\sum_{j=i}^{n} W_{ij} - \bar{X}\sum_{j=i}^{n} W_{ij}) / (\left[n\sum_{j=i}^{n} W_{ij} - (\sum_{j=i}^{n} W_{ij})^2\right] / (n-1))^{\frac{1}{2}} \tag{7}$$

$$\bar{X} = \sum_{j=1}^{n} X_j / n; S = (\sum_{j=1}^{n} x_j^2 / n - (\bar{X})^2)^{\frac{1}{2}} \tag{8}$$

In the equation, X_j represents the attribute value of the j element, W_{ij} represents the spatial weight between elements i and j, N is the total number of elements, and X is the mean value of the Z elements. The statistic G_i^* is the score, and S is the standard deviation of the elements. The closer the score is to a high-value cluster, the higher the score Z; conversely, the closer it is to a low-value group, the lower the score Z.

3.6. Selection and analysis of driving factors

The rural occupational and residential function-efficiency index emphasizes the coordination between employment and residence. The spatial arrangement of rural residents' employment and residence is closely related to natural geography, socio-economic development, and external factors. Therefore, based on the theory of occupational and residential balance and rural development theory, combined with the actual situation in Jilin Province, five primary driving indicators were selected: resource environment, social public services, economic level, external factors, and emerging factors. Eighteen secondary indicators were initially chosen, and after Pearson and Geodetector analysis, four indicators

with insignificant influence levels were eliminated. The selected indicators are shown in Table 1 (all charts and figures were created by this study based on real data).

Table 1. Driving Indicators of Rural Occupational and Residential Function-Efficiency Index in Jilin Province

Primary Indicators	Secondary Indicators	Explanation of Indicators
Resource and environmental factors	X1: Altitude	Average elevation of the county (m)
	X2: Slope	Average slope of the county (°)
	X3: Rainfall	Average annual precipitation (mm)
Social public service factors	X4: Education development level	Total number of primary and secondary schools in the county/total population*10000 (%)
	X5: Social Welfare Level	Number of beds in social welfare adoptive units/total population (number of beds/million people)
	X6: Healthcare	Number of beds in medical and health institutions/total population (number of beds/million people)
Economic Level Factor	X7: GDP per capita	Ratio of county GDP to county resident population (yuan/person)
	X8: Industrial structure	Value added of secondary and tertiary industries/GDP (%)
	X9: Ratio of income of urban and rural residents	Urban disposable income/rural disposable income (%)
External Factors	X10: Per capita fiscal expenditure	County local fiscal expenditure/county resident population (yuan/person)
	X11: Transportation accessibility	Distance from county government to provincial capital city(km)
Emerging Factors	X12: Level of technological development	Scientific and technological expenditure in the general budgetary fiscal expenditure (yuan)
	X13: Communication level	Total data communication business volume (yuan)
	X14: Level of the tertiary industry	Investment in fixed assets for culture, sports, and entertainment industries (yuan)

This study uses geographical detectors to further analyze the factors affecting the rural occupational and residential function-efficiency index based on Pearson correlation research. The geographical detector method elucidates the potential causes of spatial differentiation in geographical elements or phenomena. Since complex coupling mechanisms exist between influencing factors, which can cause multicollinearity problems, the use of geographical detectors can avoid this issue. In addition to identifying the primary influences of individual variables, geographical detectors also identify and compare the effects of various variables when they interact.

4. Results and Analysis

4.1. Synergistic Relationship of Functional-Efficiency Tradeoffs of Rural Occupation and residential in Jilin Province

Synergy and trade-off analysis was conducted for the rural occupational and residential function-efficiency indices for the periods 2008-2015 and 2015-2021. The results show that counties in the central region exhibit higher levels of synergy than peripheral areas. The function-efficiency index transitions from synergy to trade-off relationships as it extends from central counties to surrounding areas, displaying a positive correlation with the spatial distribution of the function-efficiency index. This distribution pattern reflects the influence of geographical location and resources on occupational and residential function efficiency. Central counties, with their advantageous geographical location, stronger

economic foundation, and better social services, are able to attract more people for employment and residence, thereby achieving simultaneous improvement in both function and efficiency. In contrast, peripheral counties, which have limited resources and insufficient economic development and public services, are more likely to experience a trade-off in the function-efficiency index.

As shown in Figure 3, the results show that during 2008-2015, three counties had a high-level trade-off between their rural occupational and residential function-efficiency indices (Longjing, Taonan, and Changbai Korean Autonomous County). Sixteen counties had mid-level trade-offs, eleven counties had low-level trade-offs, nineteen counties had low-level synergy, seven counties had mid-level synergy, and four counties had high-level synergy. From 2015 to 2021, fifteen counties had mid-level trade-offs, twelve counties had low-level trade-offs, nineteen counties had low-level synergy, eight counties had mid-level synergy, four counties had high-level synergy, and two counties had significant synergy. The average synergy-trade-off level for all 60 counties was 1.05 from 2008 to 2015 and 3.10 from 2015 to 2021, indicating that the level of synergy between the rural occupational and residential function-efficiency indices has gradually increased over time. The results indicate that the synergy of the occupational and residential function-efficiency index in Jilin Province is gradually improving. From 2008 to 2015, many counties were in a trade-off state, especially those with weaker economies. With the advancement of policies and improvements in infrastructure, more counties shifted from trade-off to synergy between 2015 and 2021, gradually achieving a balance in occupational and residential function efficiency. This change is mainly attributed to government investments in infrastructure, public services, and economic development, particularly in remote and economically underdeveloped areas. Additionally, the implementation of targeted poverty alleviation and rural revitalization strategies has created more job opportunities and improved living conditions, promoting coordinated development in occupational and residential function efficiency. In the future, continued support for economically weak areas is needed to reduce regional disparities and promote overall rural development.

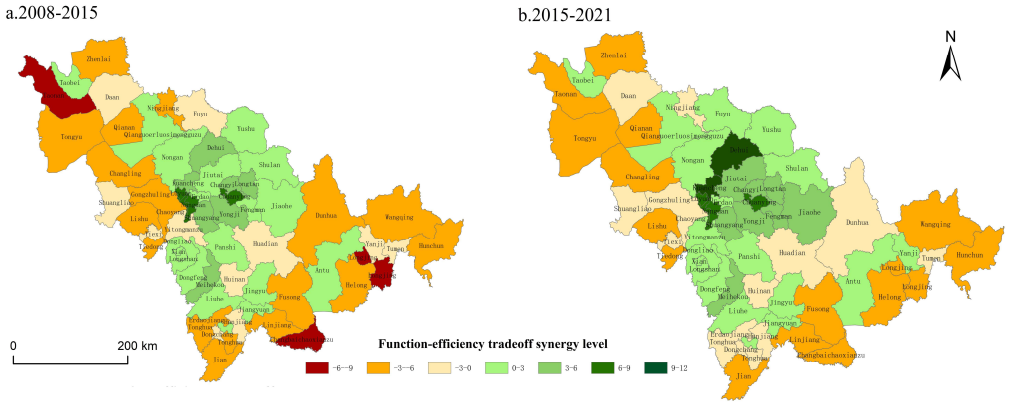

Fig. 3. Synergistic rank of occupational and residential function-efficiency index trade-offs in rural counties of Jilin Province

4.2. Spatio-temporal pattern of occupational and residential function-efficiency trade-offs in rural counties in Jilin Province

4.2.1. The overall level of occupational and residential function-efficiency index in rural counties shows an upward trend, and the spatial difference is obvious.During the study period, the overall rural occupational and residential function-efficiency index in Jilin Province showed an upward trend. From 2008 to 2021, the index increased by 9.21%, rising from 0.746 to 0.810. Using the natural breaks method, the rural occupational and residential function-efficiency index was divided into three levels:

Low (<0.80), Medium (0.80-0.90), and High (0.90-1.00) (Figure 4). From 2008 to 2021, the index displayed significant spatial differences, with a spatial pattern of "high in the center, low in the surrounding areas." Counties in the central part exhibited the strongest synergy, followed by counties in the southeast and northwest.

Counties with strong economic vitality in the central urban areas had relatively high rural occupational and residential function-efficiency indices. The proportion of rural laborers employed within the county was much higher in the central urban areas than in the southeastern and northwestern regions. This suggests that population aggregation in central urban areas provided abundant labor resources for rural development, supporting the conclusion that central counties, with better residential environments and increased non-agricultural employment opportunities, have stronger occupational-residential functions .

The rural occupational and residential function-efficiency index in the surrounding counties showed a significant upward trend. After the full implementation of the targeted poverty alleviation strategy in 2015, the growth trend of rural residential-employment coordination in the southeastern part became evident. By 2021, although the rural occupational and residential function-efficiency index in the southeast and northwest regions still lagged behind the central region, the growth rate of the index in these areas exceeded that of the central region.

Overall, the rural occupational and residential function-efficiency index remained at a relatively low level. In 2021, among the 60 counties studied, only 10 counties had a high index level, with 5 located in Changchun and 5 in Jilin City. The remaining 50 counties were at medium to low levels, primarily located in the peripheral and "two-wing" regions, which are far from the central urban areas and have weaker economic foundations.

In general, the residential and employment situation in Jilin Province's rural areas remains quite severe, with a significant proportion of rural laborers still working outside their home counties. This is especially true in the northwest and southeast regions, indicating the need to improve the rural occupational and residential function-efficiency index in these areas.

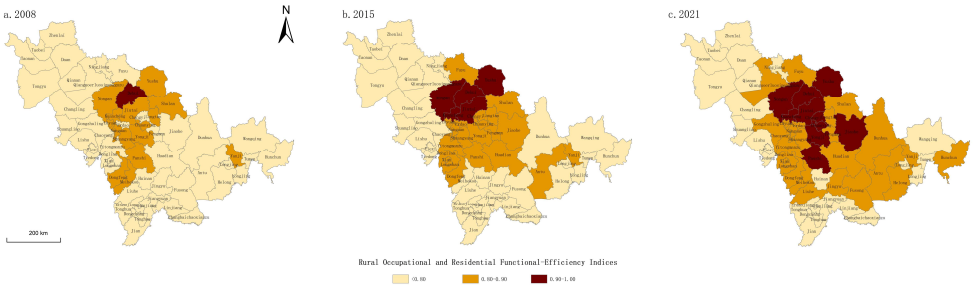

Fig. 4. Spatial Patterns of County Rural Occupational and Residential Functional-Efficiency Indices in Jilin Province, 2008, 2015 and 2021

4.2.2. The Rural Occupational and Residential Function-Efficiency Index in Jilin Province Exhibits Strong Spatial Correlation.Global autocorrelation analysis results show that the Moran's I scores for each study period were significant (P<0.05), and the coefficients for each period were all greater than 0. After iterations, the Z-scores for the three study periods were 4.03, 4.73, and 5.27, respectively, indicating spatial clustering of the rural occupational and residential function-efficiency index.

Hotspot (high-value) areas were concentrated in central Jilin Province and the Changchun area during all three periods, while coldspot (low-value) areas were mainly concentrated in the northwest of Jilin Province, where the development of the rural occupational and residential function-efficiency index was slower than in other regions. From 2005 to 2021, the range of hotspots gradually expanded,

while the range of coldspots gradually contracted, with little spatial change observed in the eastern regions of Jilin Province (Figure 5).

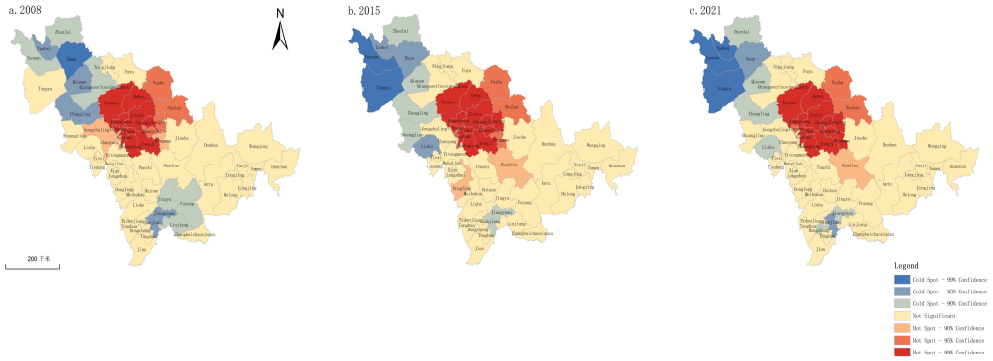

Fig. 5. Distribution of Cold and Hot Spots in County Rural Occupational and Residential Function-Efficiency Index, Jilin Province, 2008, 2015 and 2021

4.3. Comprehensive Analysis of the Driving Factors of the Rural Occupational and Residential Function-Efficiency Index in Jilin Province

In order to determine the influence of each indicator on the rural occupational and residential function-efficiency index, Pearson correlation analysis was performed, revealing significant differences in the impact of various factors across time and space. Some factors had a positive influence on the index, while others had a negative impact (Table 2). To test the robustness of the driving factors, the geographical detector model was used for further analysis. The results (Table 3) were generally consistent with the Pearson correlation analysis.

Different driving factors had varying degrees of influence on the rural occupational and residential function-efficiency index. Both the Pearson correlation analysis and the geographical detector model show that the coefficients and q-values of various influencing factors fluctuated during the study periods.

In the early stage of the study, several driving factors had a significant impact on the rural occupational and residential function-efficiency index. Among the resource and environment factors, precipitation (X3) had a notable impact with a q-value of 0.348; among the public social service factors, education development level (X4) was significant, with a q-value of 0.304; and among economic factors, industrial structure (X8) was significant, with a q-value of 0.333. Among external factors, per capita fiscal expenditure (X10) had the highest impact, with a q-value of 0.375. Among the emerging factors, the level of the tertiary industry (X14) has a significant impact, with a q-value of 0.328.

In the later stage of the study, the influence of social public service factors and emerging factors has significantly increased, while the impact of resource and environmental factors has weakened. By 2021, the influence of three driving factors within resource and environmental factors on the Rural Occupational and Residential Function-Efficiency Index had decreased to varying degrees compared to 2008. In contrast, the impact levels of social public service factors and emerging factors on the index have increased since the beginning of the study, particularly the education development level (X4) among social public service factors and the technological development level (X11) among emerging factors. Their q-values increased from 0.304 and 0.215 in 2008 to 0.445 and 0.345 in 2021, respectively. This indicates that, over time, rural residents have increasingly prioritized social service levels and emerging factors over the living environment when choosing employment and residence.

By 2021, economic factors and external factors had a relatively stable overall impact compared to 2008, but the influence of per capita GDP (X7, q=0.159) had significantly decreased from 2008

(q=0.252). In contrast, the influence of industrial structure (X8, q=0.333) remained steady, suggesting that rural residents placed more importance on the rationality of the industrial structure.

In addition, Additionally, Pearson correlation analysis (Table 2) shows that altitude (X1), slope (X2), and transportation accessibility (X11) were negatively correlated with the rural occupational and residential function-efficiency index across all three study periods. This indicates that increases in altitude, slope, and the distance to the provincial capital have negative effects on rural residents'decisions to live and work locally.

Table 2. Pearson Analysis of Driving Indicators of Rural Employment and Residence Functional-Efficiency Index in Jilin Province

Driving factors	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
2008	-0.293*	-0.297*	0.404***	0.334**	0.237*	-0.274*	0.203*	0.306**	-0.372**	0.654***	-0.272*	-0.259*	0.296	0.328*
2015	-0.208*	-0.186	-0.372**	0.372**	-0.162	-0.231*	0.133	0.316**	-0.296*	0.554***	-0.308**	0.276	-0.318*	0.453**
2021	-0.245*	-0.188	-0.373**	0.528**	0.211*	0.104	0.175	0.427***	-0.290*	0.577***	-0.302*	0.385	0.283*	0.496*

*, **, *** are significant at test levels of 0.05, 0.01, and 0.001, respectively.

Table 3. Geodetector analysis of indicators driving the rural occupational and residential function-efficiency index in Jilin Province

Influencing factors		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
2008.000	q	0.381	0.171	0.348	0.304	0.103	0.101	0.252	0.222	0.245	0.375	0.236	0.215	0.275	0.342
	p	0.000	0.003	0.000	0.000	0.000	0.004	0.016	0.014	0.000	0.000	0.058	0.000	0.003	0.000
2015.000	q	0.201	0.140	0.214	0.397	0.119	0.192	0.268	0.412	0.279	0.343	0.343	0.246	0.367	0.359
	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.012
2021.000	q	0.276	0.091	0.326	0.445	0.103	0.116	0.159	0.415	0.265	0.326	0.277	0.345	0.292	0.375
	p	0.000	0.008	0.000	0.015	0.027	0.098	0.070	0.002	0.000	0.000	0.000	0.000	0.000	0.030

Considering that the effect of 2021 geographic exploration on the driver of rural occupational and residential function-efficiency index is better and the q value is higher, the interaction driving mechanism of rural occupational and residential function-efficiency index was analyzed based on the 2021 factor. The results of interaction detection showed that the driving force of two-factor interaction had a greater effect on the county rural occupational and residential function-efficiency index than the single-factor interaction (Figure 6). In terms of factor interactions, the factors with the largest driving levels are education development level (X4) and per capita financial expenditure (X10), and when these two factors interact with other factors, their q-values increase significantly by several folds compared to when they act alone. The interaction of industrial institutions (X8) and per capita fiscal expenditure (X10) has the largest driving level, with a q-value of 0.749. The results of the study show that the q-values all tend to increase under the synergistic effect of the driving factors, suggesting that

the divergence of the rural occupational and residential function-efficiency indices in Jilin Province is affected by the combined effect of a variety of driving factors.

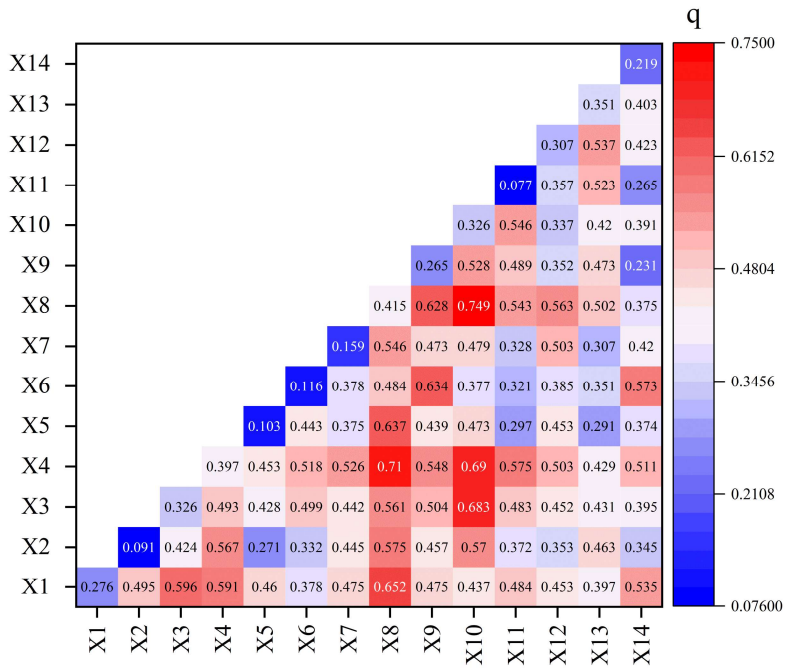

Fig. 6. Interaction probing analysis of the drivers of the rural occupational and residential function-efficiency index in Jilin Province in 2021

4.4. Classification analysis of the drivers of the rural occupational and residential function-efficiency index

4.4.1. Resource and Environment Drivers.Resources and the environment, as the foundation of human life, play both a promoting and inhibiting role in the coordination of residential and employment functions. The results of this study show that altitude and slope factors were negatively correlated with the rural occupational and residential functional-efficiency index over the three-year period, and precipitation changed from a positive correlation in the early stages of the study to a negative correlation in the later stages. This indicates that unfavorable conditions for habitation and agricultural development severely constrained the level of the rural occupational and residential functional-efficiency index. These findings are consistent with some studies, which suggest that resource and environmental factors influence whether farmers are willing to live in a particular area. In many regions of China, especially in mountainous and hilly areas, high altitude, steep slopes, and fragile ecological environments result in low levels of resource development and utilization, which significantly impact residents' safety, convenience, and production conditions. Compared to plains, the complex geographical conditions in hilly and mountainous areas, combined with fragmented land, reduce the accessibility of farmland and hinder the ease of agricultural machinery operations. High altitudes, steep slopes, and heavy rainfall decrease the level of the rural occupational and residential functional-efficiency index, particularly in the southeastern regions of Jilin Province, where altitude has the greatest impact. Therefore, effectively and reasonably developing county-level resources to address the challenges posed by altitude, slope, and elevation factors is a key consideration for achieving sustainable rural development at the county level.

4.4.2. Social Public Service Drivers. During the study period, the influence of public social services on the rural occupational and residential functional-efficiency index continuously increased. This suggests that the higher the level of education, social welfare, and healthcare in a county, the more willing people are to live and work in that county. This finding aligns with some conclusions, which state that with the ongoing urbanization process, the interests of China's migrant population are no longer limited to economic benefits; social benefits, especially access to basic urban public services, have become a new primary demand. The study found that after 2015, the impact of education development significantly increased, and the relationship between social welfare and healthcare levels shifted from being negatively correlated with the rural occupational and residential functional-efficiency index to being positively correlated. This change may be attributed to China's full implementation of the targeted poverty alleviation strategy in 2015, which addressed issues such as ensuring adequate food and clothing for the rural poor, providing compulsory education, basic healthcare, and safe residential. As a result, the level of public social services in rural counties was significantly improved. However, compared to central counties, there remains a gap in infrastructure and public service provision between the southeastern and northwestern regions of Jilin Province. The differences in public social service conditions between counties could have a significant impact on future rural population movements. The study suggests that livability and public social service conditions at the county level will be key issues for future rural development.

4.4.3. Economic Drivers. Economic factors have consistently played an important role in influencing the rural occupational and residential functional-efficiency index, but the impact of different economic factors has varied over time. As time has passed, the influence of variables such as per capita GDP and the urban-rural income ratio has gradually decreased, while the influence of the industrial structure variable has steadily increased. The prosperity of industries is a key driving force for rural development and is also an important indicator of the sustainable development of a region. The integration of industries within urban areas provides occupational opportunities close to home, helping people avoid long commutes. This principle is equally applicable to rural areas. If there are not enough occupational opportunities nearby, farmers are forced to travel long distances to cities for work, which creates a mismatch between where people live and work, lowering the rural occupational and residential functional-efficiency index. The income gap between urban and rural residents is a major factor contributing to the outflow of the rural population. The urban-rural income ratio has a significant negative correlation with the rural occupational and residential functional-efficiency index. This indicates that reducing the urban-rural income gap and improving the well-being of farmers can effectively promote local employment for rural residents and facilitate rural population retention.

4.4.4. External Drivers. The study found that external factors also play an important role in influencing the county-level rural occupational and residential functional-efficiency index. Per capita fiscal expenditure reflects the level of financial support provided by the government to the local area. Through policy guidance, the government transfers funds to rural areas, providing financial resources for rural development, which helps to improve basic public services, promote rural industrial development, and enhance people's quality of life. The results show that, although the influence of per capita fiscal expenditure on the rural occupational and residential functional-efficiency index has declined, it still shows a significant positive correlation with the index during the study period. Therefore, to achieve high-quality rural development and improve the rural occupational and residential functional-efficiency index, it is necessary for county governments to maintain or increase fiscal expenditure to reshape the county's development model. Transportation accessibility reflects the market location conditions of county-level cities within the province. The results indicate that transportation accessibility consistently shows a significant negative correlation with the rural occupational and residential functional-efficiency index. This supports the views of some scholars that the closer a district or county is to the provincial capital or mega-cities, the more stable its market demand and factor supply are. This

proximity allows rural areas to benefit from the provincial capital and other central regions, providing favorable living and employment conditions in these rural areas. The study found that the impact of transportation accessibility on the rural occupational and residential functional-efficiency index fluctuated over time, showing a downward trend since 2015.

4.4.5. Mmerging Drivers. This may be related to China's full implementation of the targeted poverty alleviation strategy and the rural revitalization strategy starting in 2015.Emerging factors are playing an increasingly important role in the Rural Occupational and Residential Function-Efficiency Index, especially with the development of technology and communications and the prosperity of the tertiary industry, which have significantly improved the overall living and employment environment in rural areas. The study indicates that technological development level (X12), communication level (X13), and the level of the tertiary industry (X14) have shown a growing impact on the Rural Occupational and Residential Function-Efficiency Index year by year, highlighting the important driving role these emerging factors play in rural development. Firstly, the technological development level has significantly improved within counties, and the correlation between technological expenditure and the index has notably strengthened in the later stages of the study. Technological advancements have not only improved agricultural productivity but have also driven the emergence of new industries, providing more high-quality job opportunities locally for farmers and reducing the need for migrant work. This suggests that technological progress is a key driver of rural economic development, enhancing both the intelligence and precision of agricultural production while laying a foundation for diversified rural economic growth. Secondly, improved communication levels have significantly influenced rural residents' quality of life and employment choices. The study found that as communication infrastructure improves, rural residents' ability to access information and engage in remote work has increased significantly. This transformation not only enhances the convenience of rural life but also creates possibilities for new forms of employment, such as remote work and e-commerce, contributing to the coordinated development of occupational and residential functions. Thirdly, the development of the tertiary industry provides significant support for enhancing the Rural Occupational and Residential Function-Efficiency Index. Increased investment in sectors such as culture, sports, and entertainment has created more employment opportunities and conveniences for rural areas, attracting more people to choose to work and live locally. The prosperity of the tertiary industry also promotes modernization in rural areas, gradually narrowing the urban-rural gap and improving residents' quality of life and well-being. Overall, the significant enhancement of emerging factors reflects the transformation and development of rural areas in the process of modernization. These factors, by providing higher levels of technology, more convenient communication methods, and a greater diversity of living and working options, have driven the coordinated development of rural occupational and residential functions. Therefore, in future rural development, investments in technology, communication infrastructure, and the tertiary industry should be further strengthened to optimize the rural occupational and residential environment, enhance residents' satisfaction with life and employment, and promote sustainable rural development.

5. Discussion

5.1. The spatiotemporal changes in the rural occupational and residential function-efficiency index.

The rural occupational and residential function-efficiency index in Jilin Province showed an overall upward trend from 2008 to 2021, with significant regional disparities in its spatial pattern. Temporally, the index displayed a pattern of gradual decline from central areas to peripheral regions. The central regions, represented by Changchun and Jilin City, demonstrated higher coordination and efficiency in occupational and residential functions compared to other regions. These areas benefit from a robust

economic foundation, well-developed public services, and abundant employment opportunities, fostering balanced and synergistic development of occupational and residential functions. However, the southeastern and northwestern regions of Jilin Province exhibited relatively low efficiency levels. Particularly, the northwest and southeast were constrained by limited natural resources and underdeveloped economic conditions, remaining in a "moderate trade-off" state for an extended period. This underscores the issue of unbalanced regional development. These findings support some scholars' conclusion that that counties with high levels of economic development can help rural development financially by strengthening the infrastructure for essential public services, improving living and working environments, and increasing rural production. During the study period, targeted poverty alleviation strategies and rural revitalization policies contributed to improvements in occupational and residential functions and efficiency in remote areas. The southeast region, in particular, experienced faster growth than the central regions, although substantial gaps between regions persist. From a hot and cold spot perspective, the hotspot areas in central regions expanded over time, while cold spots in the southeast and northwest diminished. The occupational and residential function-efficiency index in central urban areas demonstrated a stable upward trend. In contrast, despite some improvement in remote areas, further efforts are required to address key factors such as economic foundations, public service quality, and transportation infrastructure.

Overall, the population migration situation in the counties of Jilin Province is severe, with a still relatively high proportion of rural residents living and working outside their counties, especially among the labor force in the northwestern and southeastern counties. This also supports the conclusions of some scholars: due to the economic development disparities across different regions of Jilin Province, rural residents in economically developed central areas primarily live and work within their respective counties, while rural residents in the northwestern and southeastern areas predominantly live and work outside their counties. Compared to rural residents in central counties, those in the northwestern and southeastern areas tend to live farther from home for longer periods, leading to an imbalance between rural housing and employment. Therefore, it is necessary to improve the rural occupational and residential function-efficiency Index in these counties.

5.2. The driving mechanisms of the rural occupational and residential function-efficiency index.

The changes in the rural occupational and residential function-efficiency index in Jilin Province are driven by a diverse range of factors, including the resource environment, social public services, economic level, external factors, and emerging factors. These influences display varying temporal and regional characteristics. Resource environment elements, such as elevation, slope, and rainfall, to some extent restrict agricultural production and living conditions, with notable impacts on the northwestern and southeastern mountainous areas. However, their effects have gradually diminished with socioeconomic development and policy interventions. The improvement of social public services has increasingly contributed to enhancing the efficiency of occupational and residential function-efficiency index. Particularly, the optimization of education development and healthcare conditions has not only increased the attractiveness of rural areas but also improved the quality of life for residents. Economic factors have directly promoted the coordination of occupational and residential function-efficiency index, with the optimization of secondary and tertiary industries and the narrowing of urban-rural income disparities being especially critical. External factors, including government fiscal investments and transportation infrastructure, provides strong guarantees for the balanced development of rural occupational and residential function-efficiency index. This is particularly evident in remote areas, where improved public services and infrastructure have significantly alleviated imbalances in occupational and residential function-efficiency index. Additionally, emerging factors such as technological advancements, enhanced communication capabilities, and the expansion of tertiary industries have significantly modernized rural occupational and residential function-efficiency index. These factors

have improved employment and living conditions, fostering the synergistic development of occupational and residential function-efficiency index.

5.3. policy suggestions

To further improve the rural occupational and residential function-efficiency index in Jilin Province, the following policy suggestions are proposed for different driving factors: Increase investment in social public services such as education and healthcare, especially in economically underdeveloped areas in the northwest and southeast. By improving the quality of education and healthcare services, the quality of life of residents and their willingness to work locally can be enhanced, thereby improving the rural occupational and residential function-efficiency index; In terms of industrial structure optimization: Promote the development of secondary and tertiary industries, and support the industrial restructuring of underdeveloped areas. By developing non-agricultural industries and providing diversified employment opportunities, population outflow can be reduced, and economic diversity can be increased, thereby improving the rural occupational and residential function-efficiency index; In terms of government fiscal expenditure: Increase government financial investment in infrastructure and public services, especially in remote areas. Priority should be given to key areas such as education, healthcare, and transportation to ensure the effectiveness of fund utilization, thereby maximizing the improvement of the rural occupational and residential function-efficiency index; In terms of transportation and communication infrastructure: Strengthen the construction of transportation facilities and communication networks, especially in remote areas with poor transportation. By improving transportation and communication conditions, travel costs and difficulties in accessing information can be reduced, which will increase employment opportunities and improve the rural occupational and residential function-efficiency index; In terms of technological development and information and communication technology: Promote the popularization and application of information and communication technology, support the development of remote education and e-commerce, increase employment opportunities for rural residents, promote the modernization of occupational and residential functions, and improve overall efficiency; In terms of ecological protection: Emphasize ecological and environmental protection, especially in areas with poor natural conditions. Avoid environmental degradation caused by overdevelopment, advocate for green development, and ensure that economic growth and ecological protection go hand in hand to achieve a win-win situation for the rural occupational and residential function-efficiency index and ecological benefits.

6. Conclusion

This study conducted a comprehensive analysis of the spatiotemporal dynamics of the rural occupational and residential function-efficiency index in Jilin Province, while also revealing the trade-off and synergy mechanisms and driving factors of the rural occupational and residential function-efficiency index. The results show significant spatial disparities in the index across different regions, with central counties exhibiting higher efficiency levels than surrounding areas. Central regions benefit from a stronger economic foundation, better public services, and improved infrastructure, which enhances the synergy of the rural occupational and residential function-efficiency index. In contrast, counties in the northwest and southeast face resource limitations, underdeveloped economies, and insufficient public services, leading to lower efficiency and difficulties in achieving a balanced occupational and residential function. Over time, the rural occupational and residential function-efficiency index and the synergy level in Jilin Province have shown an upward trend, particularly during the period from 2015 to 2021. This improvement has mainly been driven by government policies on infrastructure development, targeted poverty alleviation, and rural revitalization. However, these improvements are not uniform, and economically weaker areas still face challenges in balancing employment opportunities and residential conditions.

The analysis of driving factors shows that economic development, public service quality, and emerging factors such as technological progress play crucial roles in influencing the rural occupational and residential function-efficiency index. Counties with better education and healthcare services show higher levels, indicating that improving social public services is critical for achieving balanced rural development. Emerging factors, especially technological progress and the development of tertiary industries, have significantly contributed to enhancing the rural occupational and residential environment. Future research should further refine the model by incorporating more relevant factors to better capture the complexity of rural occupational and residential functions. Policymakers are encouraged to tailor interventions based on the specific conditions of each county, focusing on improving infrastructure, enhancing public service quality, and promoting economic diversification to foster balanced and sustainable rural development.

This study has the following limitations: The model mainly relies on the ratio of employed population to permanent residents, neglecting key factors such as transportation accessibility and public services, which may not fully reflect the complexity of occupational and residential function-efficiency index. In spatial autocorrelation analysis, the Global Moran's I index cannot reveal local heterogeneity, and the interpretation of LISA cluster maps also involves subjectivity, affecting accuracy. Additionally, this study only selected fixed time points for analysis, which fails to capture long-term trends. The scope of the study did not delve into the differentiation between employment and residence, and policy suggestions are still in a preliminary stage. Future research should expand on model construction, spatial analysis, temporal dimensions, and policy suggestions to gain a more comprehensive understanding of the efficiency and synergy mechanisms of rural occupational and residential function-efficiency index.

Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the ongoing nature of the research.

Conflicts of Interest

The authors declare no conflicts of interest.

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