Measurement of Rural Talent Revitalization Level in China and Analysis of Spatiotemporal Characteristics

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Abstract

This thesis addresses China's Rural Revitalization Strategy by establishing talent revitalization as its core driver. An evaluation system encompassing talent support, cultivation, and effectiveness was developed. Comprehensive econometric methods assessed rural talent revitalization levels across 31 Chinese provinces (2008-2022), utilizing national statistical yearbooks and departmental Data. Results indicate a stepwise upward trend in revitalization levels. Talent cultivation contributed most significantly, driven by non-agricultural workforce size and e-commerce development. Pronounced regional disparities formed a distinct spatial pattern, with eastern provinces leading and northeastern regions lagging. Spatio-temporal analysis revealed significant spatial autocorrelation and "club convergence": high-level clusters expanded from core eastern regions to encompass ten contiguous provinces, while low-level areas spread northwest and northeast. High-performing provinces exhibited reinforcing "elite club" effects, while low-performing ones faced intensified constraints from spatial negative external influences. Key obstacles included shortages in non-agricultural talent, insufficient innovation capacity, and lagging e-commerce infrastructure. Geographically and Temporally Weighted Regression (GTWR) modeling identified widening urban-rural income gaps, topographic relief, and environmental pollution as significant inhibitors. Conversely, rural fixed asset investment and population density exerted positive, though spatio-temporally heterogeneous, effects. Proposed interventions include: establishing "talent innovation enclaves" and tax-sharing schemes for East-West resource flow; creating "traditional industrial base talent zones" to revitalize the northeast; exploring human capital conversion mechanisms in border regions; building county-specific industrial talent matrices; implementing a Digital Commerce Initiative 2.0 for a data-skill-market loop; innovating urban-rural talent rotation with property-right incentives; establishing rural teconology incubators; piloting "carbon sink-for-talent" trading; and building digital twin policy systems for precision governance. This research provides theoretical and practical foundations for optimizing rural talent allocation and promoting regional coordination.

Key words: Rural revitalization; Talent revitalization; Evaluation indicator system; Level measurement; Spatiotemporal characteristics

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List of Abbreviations

MCDM	Multiple Criteria Decision Making
PCA	Principal Components Analysis
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
GRA	Grayscale Association Analysis
DEA	Data Envelopment Analysis
CV	Coefficient of Variation
KDE	Kernel Density Estimation
GWR	Geographically Weighted Regression
TWR	Temporally Weighted Regression
GTWR	Geographically and Temporally Weighted Regression
OLS	Ordinary Least Squares Regression
VIF	Variance Inflation Factor
GIS	Geographic Information System

Chapter 1

Introduction

1.1. Research Background

With the advancement of poverty alleviation and the deep adjustment of the domestic economic structure, rural areas in China are facing unprecedented development opportunities and challenges (Dou et al., 2019). As a vital foundation for national economic and social development, the revitalization of rural areas is directly linked to the country's sustainable development and comprehensive modernization process (Zhang, 2018). In 2017, the Report to the 19th National Congress of the Communist Party of China first proposed the "Rural Revitalization Strategy," explicitly stating that issues related to agriculture, rural areas, and rural residents are fundamental to the national economy and people's livelihoods. It is imperative to always prioritize addressing the "Three Rural Issues" as the top priority of the Party's work and implement the Rural Revitalization Strategy. The proposal of this strategy marks a new historical stage for rural development in China, providing a clear direction and policy support for the comprehensive revitalization of rural areas (Xi, 2017). The Rural Revitalization Strategy is proposed not only to address current imbalances in urban-rural development and lagging rural economic development but also to achieve the country's long-term development goals (Ye, 2018). The core objectives of the strategy are to achieve prosperous industries, livable ecology, civilized rural customs, effective governance, and affluent lives in rural areas. The realization of these objectives requires concerted efforts from all sectors, with rural talent serving as a key link (Huang, 2018).

As a crucial component of the Rural Revitalization Strategy, rural talent revitalization plays an irreplaceable role in achieving all objectives of rural revitalization. Only through talent revitalization can rural areas be provided with a continuous supply of intellectual support and innovative momentum, driving the sustainable development of the rural economy and comprehensive social progress. Specifically, rural talent revitalization can promote the upgrading and transformation of rural industries, improve agricultural production efficiency and quality, and advance the integrated development of rural primary, secondary, and tertiary industries; it can enhance the level of rural public services, improve rural education, medical care, culture, and other conditions, and enhance the sense of gain and happiness among rural residents; it can inherit and promote excellent rural traditional culture, strengthening the cohesion and influence of rural culture; and it can improve rural governance capabilities, promoting harmonious and stable rural societies (Zhou, 2019). Only by attaching great importance to rural talent revitalization, taking effective measures to strengthen talent cultivation and introduction, and optimizing the talent development environment can new vitality be injected into rural development, promoting rural economic prosperity and comprehensive social progress, and ultimately achieving the sustainable and comprehensive revitalization of rural areas.

Currently, rural talent revitalization faces numerous challenges, such as the migration of rural labour to cities and the incomplete talent cultivation and incentive mechanisms, which restrict the progress of rural talent revitalization and further affect the implementation effect of the Rural Revitalization Strategy (Pu et al., 2018). Therefore, it is important to understand the connotation of rural talent revitalization, how to measure its level, and its temporal evolution, regional variations, and spatio-temporal distribution characteristics. Understanding the above issues is crucial for advancing rural talent revitalization.

1.2. Research Objectives and Significance

1.2.1. Research Objectives

Against the backdrop of comprehensive rural revitalization, this thesis centres on the core theme of rural talent revitalization, constructing a research framework and paradigm for rural talent revitalization along the logical main line of "theoretical mechanism analysis → comprehensive measurement of elements → spatio-temporal characteristic analysis → driving mechanism identification", and deeply interpreting the theoretical logic and path selection for the realization of rural talent revitalization. Specifically:

(1) Constructing a scientific and reasonable index system for rural talent revitalization and conducting empirical measurement of its development level. Based on a systematic review of relevant theories and literature on rural talent revitalization, and combined with the actual situation of rural talent revitalization in China, representative, operable, and quantifiable indicators for rural talent revitalization are selected. Scientific and objective methods are adopted to determine the weights of each indicator, and an index system for rural talent revitalization is constructed. Through the collection and collation of rural talent revitalization data from different regions and years, comprehensive evaluation methods and other approaches are used to conduct empirical measurement of the development level of rural talent revitalization, analyse its development trend characteristics and regional differences,

reveal the differences and changing trends of rural talent revitalization levels in different regions and years, and provide basic data for follow-up research.

(2) Relying on the measurement results, with the aid of statistical models and GIS analysis tools, systematically exploring the spatio-temporal characteristics of rural talent revitalization. Statistical analysis models such as the Dagum Gini coefficient, kernel density estimation, and the spatial Markov transition matrix are used to conduct in-depth analysis of the overall characteristics of rural talent revitalization, revealing its internal structure and laws. Meanwhile, GIS technology is utilized to visualize the spatial pattern distribution, spatial agglomeration evolution, and spatial directional evolution of rural talent revitalization, revealing the spatio-temporal differentiation and evolution laws of rural talent revitalization in China from multiple perspectives. The systematic study of the spatio-temporal characteristics of rural talent revitalization provides a scientific basis for formulating targeted rural talent revitalization strategies.

(3) Based on the measurement results, from the unique perspective of spatio-temporal effects, deeply analyzing the influencing factors and internal operation mechanisms of the evolution of rural talent revitalization levels in both temporal and spatial dimensions. Appropriate models, such as the obstacle factor model and geographically and temporally weighted regression model, are selected to conduct in-depth analysis of the obstacle factors and influencing factors of the evolution of rural talent revitalization levels, revealing their internal operation mechanisms. On this basis, combined with the measurement and analysis results, targeted optimization strategies and paths are proposed to provide practical guidance for the implementation of rural talent revitalization and the Rural Revitalization Strategy.

Through this study, it is expected to provide new perspectives and methods for rural talent revitalization research, offer a scientific basis and empirical data for government departments to formulate relevant policies, and contribute to promoting the implementation of rural talent revitalization and the Rural Revitalization Strategy.

1.2.2. Research Significance

The Rural Revitalization Strategy is a major national policy aimed at the comprehensive development and prosperity of rural areas. Despite notable successes in its implementation such as infrastructure development (Han et al., 2018) and poverty alleviation (Yang et al., 2020), the rural talent revitalization continues to face significant challenges including brain drain and an aging workforce (Ma et al., 2019). How to promote rural talent revitalization efficiently and sustainably has become a key topic of concern for academics and policymakers. Therefore, in-depth exploration of the level and spatio-temporal evolution characteristics of rural talent revitalization in the new era not only holds important theoretical value but also has far-reaching practical significance.

(1) Theoretical Significance

Firstly, enriching the evaluation system and research content framework of rural talent revitalization. Current academic research on rural talent revitalization mainly focuses on conceptual connotations and development paths, with relatively few quantitative evaluations of its level (see sections 1.3.1 and 1.3.2 of the thesis). Based on a systematic analysis of the connotations and characteristics of rural talent revitalization, this study constructs a measurement system and evaluation model for rural talent revitalization, conducting comprehensive systematic assessments, spatial disparity analyses, and influencing factor studies at the provincial level in China. This not only enriches the evaluation system of rural talent revitalization but also expands its research framework, providing new analytical ideas and methods for quantitative studies and facilitating deeper research development.

Secondly, improving the methodological system of rural talent revitalization research. The current quantitative research on rural talent revitalization is still weak, and relevant methodological studies urgently need enhancement (see section 1.3.3 of the thesis). This study employs comprehensive evaluation methods, obstacle degree models, Dagum Gini coefficients and kernel density estimation for comprehensive evaluations, and attempts to use geographical spatial analysis methods to analyse the spatio-temporal patterns and evolution characteristics of rural talent revitalization. It also applies geographically and temporally weighted regression models to explore influencing factors and spatial heterogeneity. The introduction of these methods offers new perspectives and methodological guidance, providing reference for future studies on rural talent revitalization across different scales and contexts, and contributing to improving the nature and accuracy of scientific research.

(2) Practical Significance

Firstly, comprehensively understanding the current status of rural talent revitalization. Through the measurement of rural talent revitalization levels, a comprehensive and clear understanding of regional development can be obtained. Rural revitalization is a theme, task, and goal for China's development during the "14th Five-Year Plan" period and beyond, and a major strategy related to China's modernization process. Guided by relevant disciplinary theories, constructing a development index evaluation system and model for comprehensive measurement and comparative analysis helps understand the overall development and regional imbalance of rural talent revitalization, clarify development statuses, weak links, and constraints in various regions, and propose targeted countermeasures. This is of great practical significance for achieving rural talent revitalization, providing a scientific basis for government policy formulation and promoting effective implementation.

Secondly, providing a decision-making basis for strategic planning. With the implementation of the Rural Revitalization Strategy, the state has introduced a series of policies, but talent shortages remain a core bottleneck restricting rural sustainable development. This study, through spatio-temporal characteristic research, deeply explores the mechanism of rural talent revitalization, clarifies the changing trends of spatio-temporal relationships, analyse key influencing factors, and implements them in specific spatial units. On the one hand, it finds theoretical breakthroughs for regional issues; on the other hand, proposing optimization paths and policy suggestions from multiple perspectives provides empirical support for spatial optimization and decision-making references for government strategic planning. This is of important practical value for promoting rural talent revitalization and the implementation of the Rural Revitalization Strategy, assisting governments in formulating and implementing policies to facilitate comprehensive rural development and prosperity.

1.3. Research Review

1.3.1. Research Status of Rural Talent Revitalization

As the core topic of the Rural Revitalization Strategy, the revitalization of rural talents has received extensive attention from the academic community in recent years, and the research perspectives cover multiple dimensions such as theoretical mechanisms(Han, 2023;Xu, et al., 2024;Pan, 2025), practical paths(Dong, 2022;Wu, et al., 2024;Feng, et al., 2025), and policy innovation(Tian, et al., 2020;Zhang, et al., 2023;Xu, et al., 2024), and a series of insightful achievements have been formed. The existing literature focuses on the connotation and extension of rural talent revitalization, focusing not only on the empirical refinement of local practices, but also on cross-regional and cross-national comparative analysis, and at the same time, combined with emerging concepts such as digital technology and new endogenous development theory, a multi-level and multi-dimensional research framework is constructed.

At the level of the theoretical mechanism, scholars emphasize the role of digital technology in promoting the revitalization of rural talents. Li et al.(2023) put forward the construction path of the new farmer cultivation cycle in the context of "digital business to rejuvenate agriculture", emphasizing that digital technology needs to run through the whole life cycle of talent cultivation, and realize the overall improvement of the quality and efficiency of human capital by enhancing identity, expanding multilateral cooperation, building a technical framework, and building a talent pool. This view is further extended in the research of Pan(2025) which starts from the triple empowerment dimensions of psychology, resources, and structure, pointing out that digital technology activates endogenous motivation by improving local talent skills and entrepreneurial vitality, and at the same time attracts foreign elites to introduce new technologies and new ideas, and builds a dynamic and balanced rural talent ecosystem with the help of the platform economy and sharing economy theory. In addition, new endogenous development theories have been introduced to reconcile the contradictions between traditional "exogenous" and "endogenous" mechanisms. Han(2023) advocates abandoning the limitations of one-way dependence on external inputs or internal self-generation, and promoting the coordinated development of internal and external talents through education, training, and urban-rural resource linkage, forming a hybrid path of "upper and lower linkage, internal and external symbiosis". Xu et al.(2024) focuses on the urban-rural mobility of the "related population", expands the main body of rural talent revitalization to loose and close groups with native or foreign ties with the countryside, and proposes a strategy to guide the "related population" to participate in rural construction by classification, which provides a new idea for solving the problem of the lack of subjects.

The research on the practice path mostly focuses on local policy innovation and typical case analysis, revealing the importance of the coordination between government guidance and market mechanism. Zhejiang Province's "Agricultural Maker" policy has successfully shaped a rural youth talent cultivation model of targeted talent introduction, drip irrigation and embedded talent retention through precise focus, professional improvement and diversified development strategies, and its experience shows that the deep integration of youth, entrepreneurship, science and technology and other elements is the key to opening up a new path for rural common prosperity (Feng et al., 2025). The "rural CEO" model in Yunnan verifies the central role of management talents with the characteristics of "high embeddedness and high publicity" in the integration of collective assets and the endogenous development of rural areas through the embedding of institutional subjects and structural functions (Wu et al., 2024). The practical experience of the rural professional manager system in Yuhang District, Zhejiang Province further shows that innovative operation concepts, coordination of multi-subject participation and government support are the key elements to empower rural operations, and its market structure of "selection, education, use, and retention" and the operation mechanism of "institutional traction-resource supply-rational action" provide a replicable governance template for similar areas (Sun et al., 2024). For example, Japan's "hometown working holiday" system attracts urban youth to return to their hometowns through special industrial projects (Dong 2022), and the Korean new village mentor training model realizes talent revitalization by strengthening the vitality of villages (Xuan et al., 2022), all of which suggest that China needs to pay attention to the combination of regional characteristics and multiple collaborative strategies in policy design to broaden the channels for talent return. The education system is regarded as the basic support for the revitalization of rural talents, and the functional orientation and reform path of vocational education and higher education have become the focus of research. In terms of vocational education, Chen(2022) pointed out that the current vocational education is facing practical difficulties such as insufficient attraction, suboptimal curriculum resources, and rigid training models, and proposes that it is necessary to improve adaptability by optimizing professional settings, innovating "school-village-enterprise" order-based training, and strengthening local technical services. Based on the new endogenous development theory, Zhao et al.(2024) advocate that vocational education should build an agriculture-related professional cluster, deepen the practical teaching of the integration of autonomy, rule of ethics and rule of law, and build a solid spiritual foundation for talents by arousing the identity of local culture. Li et al.(2021) put forward the need to solve the four problems of "retention, reliability, sinking, and exit" in vocational education in ethnic areas, emphasizing the integration of personalized training of skilled talents and local responsibility for education. The role of higher education is reflected in the diversified service provision. Sun(2024) systematically sorted out the contribution of measures such as the special post teacher program, the publicly-funded normal student policy, and the "one village one college student" project to the rural human capital reserve. Qiao et al.(2022) found that the "one village, one college student" project can significantly promote farmers' entrepreneurship, and its mechanism is to alleviate land and capital constraints, highlighting the unique value of higher education in solving the structural shortage of rural talents. In addition, the construction of a village-level education service system by the Open University (Su et al., 2020) and the implementation of the path of "precise enrollment→ training →and employment" in higher vocational colleges (Li et al., 2021) show that the in-depth connection between education supply and actual rural demand is the core to improve the effectiveness of talent cultivation.

The research on practical challenges and countermeasures presents distinct problem-oriented characteristics, focusing on the deep contradiction of talents "unable to introduce, retain, and use well". Typical cases such as the imbalance of talent structure, insufficient development space, and lack of incentive mechanism in key counties (Li et al., 2024), the marginalization of market logic due to the weak power of professional managers (Li, 2023), and the fragmentation of the cultivation system of high-quality farmers (Liu et al., 2022) reveal the shortcomings of institutional design and resource matching. For example, the "post-employment separation" mechanism in Sichuan Province attracts professional and technical talents to sink to the grassroots level through the flexible allocation of establishment and posts (Sun et al., 2021), and a unified and integrated governance framework needs to be constructed, such as the three-dimensional framework of "institutional supply-resource co-ordination-holistic governance" (Tian et al., 2020). At the resource level, the support of digital infrastructure and industrial platforms should be strengthened, Li et al.(2023) advocate improving farmers' digital literacy through rural network coverage and multi-subject collaboration, Zhang et al.(2024) Taking the practice of "gathering talents with culture" in Dajidian Village as an example, it is proved that the benign interaction between the cultural tourism industry and the return of talents can attract high-quality talents in the city. At the cultural level, it is necessary to reconstruct the synergy between local identity and governance, Xu et al.(2024) proposes to activate the urban-rural mobility channel of "related population", and Zhang et al.(2023) emphasizes the core role of grassroots party organizations in leading the revitalization of rural culture, and promotes the integrated development of talents and culture through institutional innovation.

1.3.2. Evaluation of Rural Talent Revitalization

In the field of talent competitiveness evaluation, scholars have constructed a multi-dimensional index system based on different theoretical perspectives and regional development needs, showing the characteristics of "theoretical consensus and path differentiation". From the perspective of research objects, Yang et al.(2024) takes innovative talents as the research object, and proposes a four-dimensional evaluation model of "scale-structure-efficiency-environment", in which the scale dimension depicts the talent base reserve through the number of R&D personnel, full-time equivalent and other indicators, the structural dimension emphasizes the coordination between the educational level (the proportion of talents with a bachelor's degree or above) and the industry distribution (the proportion of high-end manufacturing talents), the efficiency dimension quantifies the scientific and technological and economic contributions by the number of patents granted and the turnover of the technology market, and the environmental dimension focuses on the intensity of scientific research investment, the supply of higher education resources and the level of regional economy. In contrast, Zhao(2021) designed a four-dimensional framework of "resources-input-output-environment" for scientific and technological talents, with the resource dimension covering the total number of R&D personnel and the proportion of scientists, the investment dimension highlighting the proportion of fiscal science and technology expenditure, the intensity of R&D investment and other policy support, the output dimension focusing on the number of patents granted and the revenue of high-tech industries as the core to quantify the ability to transform innovation achievements, and the environmental dimension extending to soft indicators such as living facilities and policy openness.

From the perspective of the study area, Zhao et al.(2017) uses a more global three-dimensional framework of "resources-efficiency-environment" to measure the national talent competitiveness index. Si et al.(2017) constructed a five-dimensional model of "scale-structure-input-output-support" in response to the empirical needs of Shandong Province. Its innovation lies in taking "talent support" as an independent dimension, incorporating social supporting indicators such as the number of cultural institutions and social security expenditures, and highlighting the weight of scientific and technological achievement awards (national/provincial level). Hu et al.(2023) focuses on the particularity of the western region and designs a six-dimensional framework of "attraction-scale-training-configuration-structure-benefit". By adding the dimensions of "talent attraction" and "allocation", the system directly addresses the problem of brain drain and regional imbalance in the western region. Although there are differences in the division of dimensions in these studies, they all reflect the systematic thinking of "environmental support-basic stock-efficiency transformation".

Specific to the evaluation of rural talent revitalization, scholars generally regard talent revitalization as an independent dimension and combine the framework of "five revitalizations" to construct an evaluation index system for rural talent revitalization.

Hua et al. (2020) set up two first-level indicators under the talent revitalization criterion layer in the rural revitalization evaluation system built by Jiangsu Province, covering specific indicators such as per capita education investment, the number of agricultural researchers, and the number of agricultural technicians, emphasizing the supporting role of education and professional and technical talents in rural development. Li et al.(2021) further refined the secondary indicators of talent revitalization in Qinghai Province, including the proportion of farmers with junior high school education or above, the proportion of farmers with agricultural professional and technical training, and the proportion of labour transfers, revealing the key to human capital development and labour structure optimization. In addition, Zhang et al.(2021) measured the level of digital agriculture human resources in China by using indicators such as local financial education expenditure, information transmission, software and information technology service industry practitioners, and members of rural professional and technical associations. Similarly, Cai et al.(2022) selected the number of secondary education students, the proportion of students in rural working age, the proportion of employees in rural information transmission and the computer service industry, the proportion of employees in the education industry, and the proportion of employees in the science and technology service industry as specific indicators of the dimension of informatization human resources. There are also scholars who have conducted measurement studies on concepts related to the revitalization of rural talents. Liu et al.(2022) constructed a subjective and objective combined index weight model through the best-worst method and the coefficient of variation method, and analysed the development status and level of rural practical talents in various regions from five aspects: talent scale, talent structure, talent quality, talent effectiveness and talent guarantee. Wang(2022) constructed an evaluation index system for the competitiveness of agricultural science and technology innovation talents through four dimensions: talent stock competitiveness, talent efficiency competitiveness, talent environment competitiveness, and talent sustainable development competitiveness.

1.3.3. A Review of Research on the Rural Talents Revitalization

The existing research has carried out multi-dimensional exploration around the core topics such as the theoretical mechanism, practical path and evaluation system of rural talent revitalization, and has achieved fruitful results and important theoretical implications. At the level of theoretical construction, scholars have broken through the traditional dualistic thinking paradigm of "exogenous-endogenous", and constructed a hybrid model of "institutional traction-resource synergy-action embeddedness" by taking the new endogenous development theory as the analytical framework and integrating emerging perspectives such as digital technology empowerment and relational population flow (Atterton J et al., 2020). This theoretical innovation not only systematically explains the complex mechanism of talent revitalization in the context of urban-rural factor flow, but also provides a new explanatory path to solve the structural dilemma of rural talents. In the field of practical research, through the in-depth analysis of typical regional cases and the comparative study of international experience, the government policy innovation and market mechanism revealed the key role of synergy. In particular, in the refinement of experience of innovative models such as the professional manager system, the practice of integration of industry and education, and the activation of "migratory bird" talents, a governance template with regional adaptation has been formed, which provides a replicable operating paradigm for grassroots practice (Sun et al., 2007; Wang et al., 2025). In terms of evaluation system research, based on the systematic thinking of "environment-scale-efficiency", the academic community has constructed a multi-dimensional index system covering macro regional competitiveness and micro talent effectiveness, including not only a comprehensive evaluation framework for the provincial level, but also special measurement tools for digital agricultural talents, rural craftsmen and other subdivisions, so as to achieve a dynamic balance between theoretical consensus and regional adaptability (Xiao et al., 2023).

Although significant progress has been made in existing research, there are still academic blind spots that need to be broken through. First of all, the research methods are mostly limited to the perspective of a single discipline of sociology, and there is a lack of interdisciplinary research based on spatial economics, statistics and geographic information science, which makes it difficult to fully reveal the spatio-temporal differentiation law of talent revitalization. Secondly, there is an obvious scale bias in the research objects, and the existing results mostly focus on urban agglomerations or provincial macro units, while the detailed research on micro scales such as counties and villages and towns is still insufficient, which restricts the precise implementation of policy tools. Finally, the research on the impact mechanism presents the characteristics of fragmentation, and a comprehensive analytical framework covering the interaction between physical geographical constraints, socio-economic drivers and institutional environment has not yet been constructed, and there is a lack of systematic observation of the spatial spillover and time delay characteristics of policy effects.

Based on this, this study focuses on the core proposition of "measurement of rural talent revitalization level and spatio-temporal characteristics analysis", tries to construct an evaluation index system with universality and regional adaptability, and comprehensively uses spatial econometric models and geographic information technology to deeply analyse the temporal and spatial evolution law and driving mechanism of talent revitalization, in order to improve the analytical framework of rural talent development at the theoretical level and provide a scientific basis for the design of differentiated policies at the practical level.

1.4. Research Contents, Ideas and Technical routes

1.4.1. Research Contents

The main contents and structure of this study are as follows:

Chapter 1 is an introduction. This chapter aims to define the starting point of research and systematically expound the research background, purpose and significance of rural talent revitalization. Undertake literature review, sorts out domestic and foreign research trends to clarify existing shortcomings, and then establishs research entry points; Finally, the research plan is planned, and the framework structure, technical route and innovation of this work are proposed, so as to construct a logical framework for the full text.

Chapter 2 is the theoretical foundation. This chapter mainly defines the connotation of Rural Revitalization Strategy, the core concept and extension of rural talent revitalization, reviews the theoretical support of human capital theory, regional development theory and urban-rural integration development theory, constructs a theoretical model for measuring the level of rural talent revitalization, and explains the geographical differentiation theory of spatiotemporal characteristics analysis. This chapter lays a theoretical foundation for the construction of the index system and the analysis of spatiotemporal space.

Chapter 3 introduces a measure of the level of rural talent revitalization. Based on policy orientation and literature analysis, this chapter constructs an evaluation system and comprehensively uses a model that combines the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and the entropy weight method, namely the entropy weight-TOPSIS model, to conduct a comprehensive survey of the level of rural talent revitalization in 31 provinces in China from dynamic measurements bewtween 2008 and 2022. Through weight analysis, regional difference decomposition and provincial ranking evolution, the characteristics of national and sub-regional revitalization levels are revealed. The results of this chapter provide data support for the analysis of spatiotemporal characteristics.

Chapter 4 analyses the spatial and temporal characteristics of rural talent revitalization. This chapter uses the Dagum Gini coefficient decomposition method to reveal the sources of regional differences, and combines it with kernel density estimation to describe distribution dynamics. Analyse spatial correlation and aggregation patterns through global and local Moran's I index and Getis-Ord Gi* hotspot analysis. Use standard deviation ellipses and Markov chain models to explore the evolution rules of space-time directionality and transference.This chapter reveals the spatiotemporal differentiation mechanism of rural talent revitalization from multiple dimensions, and provides an empirical basis for the analysis of influencing factors.

Chapter 5 provides the factors for the revitalization of rural talents. In this chapter, we use the obstacle degree model to identify the constraints at the national and sub-regional levels, construct a geographic spatiotemporal weighted regression model, and analyse the spatiotemporal heterogeneity of the driving factors from three dimensions: economic drive, social bearer, and natural constraint. This chapter deepens the explanation of the causes of the spatiotemporal evolution in Chapter 4 and provides a basis for policy recommendations.

Chapter 6 presents the conclusions and countermeasures. This chapter reviews the research results of the full text, and puts forward countermeasures and suggestions based on the results of analysis, so as to realize a complete logical chain from theory to practice.

1.4.2. Research Ideas

On the basis of clarifying the research purpose, contents and methodology, this study is laid out according to the logical structure of problem discovery (research background and significance→ literature review→ theoretical analysis), analysis of problems (model construction→evaluation analysis) and problem solving (countermeasures and suggestions), as shown in Figure 1.1.

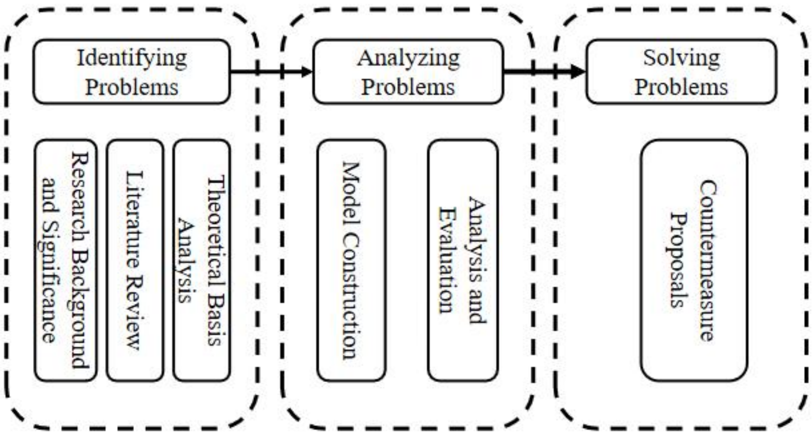

Figure 1.1: Research Idea Diagram

1.4.3. Technical Route

The technical route of this study is shown in Figure 1.2.

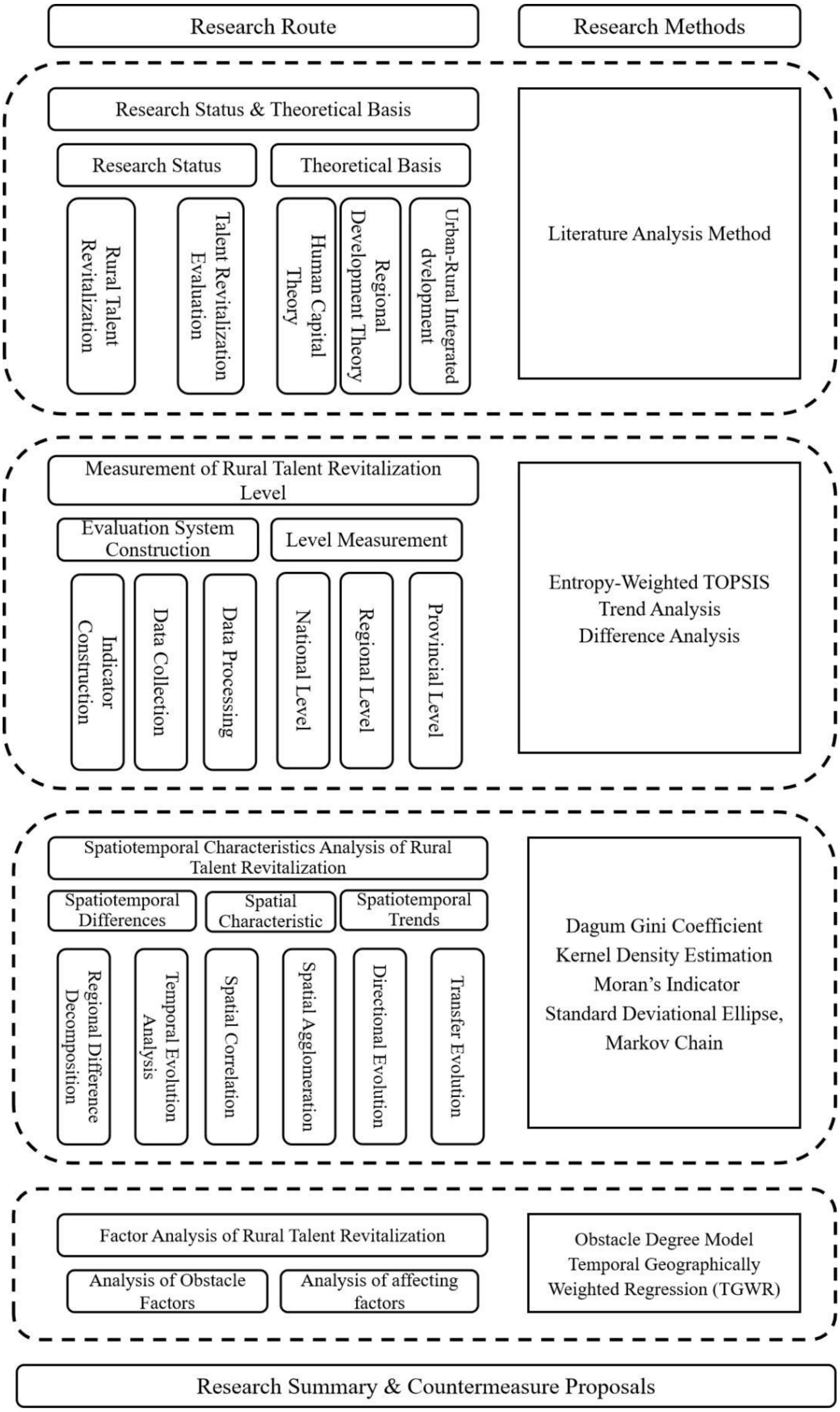

Figure 1.2: Technical road map of research

1.5. Main Innovations

Focusing on the measurement results of rural talent revitalization level, this study conducted in-depth research on the regional distribution, spatiotemporal evolution and influencing mechanism of rural talent revitalization level in China, and the main possible innovations are reflected in the following four aspects:

(1) A multi-dimensional evaluation system was constructed and the research framework of rural revitalization was expanded. This study breaks through the dependence on single-dimensional or static indicators in traditional research, and based on the three-level structure of "target layer-dimension layer-indicator layer", we innovatively construct an evaluation system for rural talent revitalization that includes three dimensions of talent guarantee, talent construction, and talent efficiency, as well as 21 specific indicators. Key indicators such as the scale of e-commerce platforms and the scale of rural governance talents are included in the measurement framework, which not only highlights the characteristics of the new era such as "digital commerce to rejuvenate agriculture", but also takes into account the needs of rural governance modernization.

(2) A spatio-temporal adaptation policy system is proposed to innovate the implementation path of rural talent revitalization. Based on the analysis of the spatiotemporal evolution law and obstacle mechanism, a differentiated policy framework is constructed: the eastern part of the country should implement the strategy of deep integration of "industrial chain and talent chain" to strengthen the radiation efficiency of the Yangtze River Delta and the Pearl River Delta to the surrounding regions; The central and western regions require a combination strategy of the "infrastructure-education investment-digital empowerment", focusing on breaking the dual constraints of industrial platforms and innovation capabilities; The northeast region needs a breakthrough plan of "institutional innovation-enclave economy-human capital activation" to reverse the low-level equilibrium caused by the

net outflow of the population. Border provinces should explore a new model of "digital infrastructure + cultural IP + cross-border collabouration" to break through the "Hu Huanyong line effect" formed by geographical constraints. The policy recommendations break through the traditional idea of homogenization and emphasize the dynamic response of spatio-temporal heterogeneity, providing an innovative practical paradigm for the revitalization of rural talents in the new era.

Chapter 2

Theoretical Basis and Conceptual Definitions

2.1. Definition of Core Concepts

2.1.1. Connotation of Rural Revitalization Strategy

The Rural Revitalization Strategy is a major strategic deployment proposed by the Communist Party of China and the state in the new era to solve the "three rural" problems and promote the integrated development of urban and rural areas (Gao et al., 2022). Its connotation not only includes the inheritance and breakthrough of the traditional rural development path, but also reflects the overall nature of socialist modernization. Since the 19th National Congress of the Communist Party of China (CPC) in 2017 first put forward the "Implementation of the Rural Revitalization Strategy", the 2018 Central Document No. 1 "Opinions of the Central Committee of the Communist Party of China and the State Council on the Implementation of the Rural Revitalization Strategy" further clarified the strategic framework, elevated rural revitalization to an important position in the modernization of the national governance system and governance capacity, marking that China's agricultural and rural development has entered a new stage of systematic reconstruction[①]. From the perspective of national policy background, the proposal of Rural Revitalization Strategy has a profound historical inevitability. In the process of the rapid urbanization over the past 40 years of reform and opening up, the contradiction between urban and rural dual structure has become increasingly prominent: on the one hand, the urban siphon effect has led to the hollowing out of the rural population, industrial decline, and ecological fragility (Shi et al., 2022); On the other hand, traditional agricultural production methods are difficult to adapt to the needs of high-quality development, farmers have narrow channels to increase income, and the inheritance of rural culture is at risk of rupture (Xue et al., 2022). In view of these structural contradictions, Document No. 1 clearly puts forward the general policy of "giving priority to the development of agriculture and rural areas", emphasizing the construction of an urban and rural community with a shared future through institutional innovation, systematic reform of policy supply and the allocation of key factors of production (such as land, labor, and capital). This strategy is not only a correction of the "urban bias" development model, but also a deepening exploration of the road of socialism with Chinese characteristics, which should not only avoid the lessons of rural decay in the process of urbanization in the West, but also break through the shackles of the traditional rural one-way dependence on the development of cities, and finally realize a new type of relationship in which urban and rural elements flow in both directions and complement each other's functions.

The "five-in-one" general requirements of the Rural Revitalization Strategy, including industrial revitalization, ecological revitalization, cultural revitalization, organizational revitalization, and talent revitalization, constitute an organic and unified logical system, as shown in Figure 2.1.

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①Central Committee of the Communist Party of China, the State Council. (2018). Opinions on the implementation of Rural Revitalization Strategy [EB/OL]. [2018-01-02]. https://www.gov.cn/xinwen/2018-02/04/content_5263807.htm.

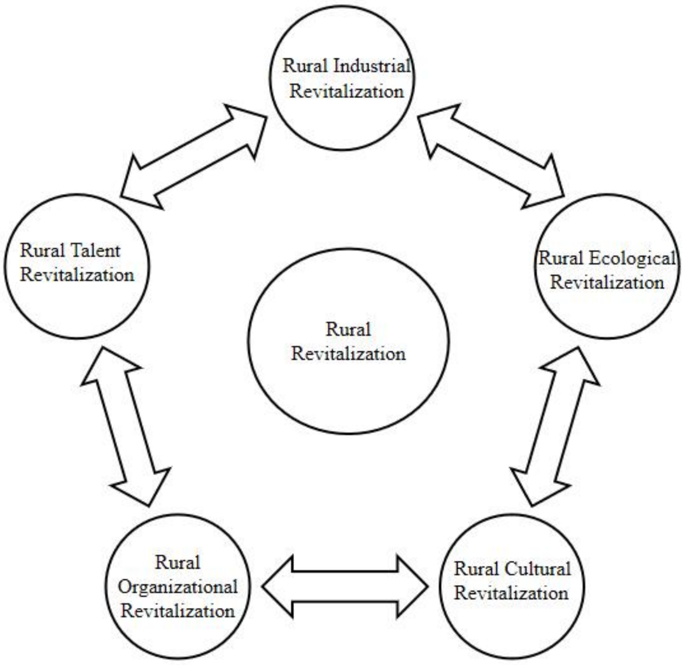

Figure 2.1: Rural revitalization "five-in-one" relationship diagram

As the economic foundation, the connotation of industrial revitalization has expanded from a single agricultural production to the construction of a modern industrial system integrating three industries. Through the development of new business formats such as characteristic agriculture, rural tourism, and rural e-commerce, the value of traditional factors such as land and labour has been activated, and new factors of production such as digital technology and social capital have been introduced (Guo et al., 2023). For example, the rise of modern agricultural industrial parks and pastoral complexes is the practical embodiment of the development concept of "succession" in industrial revitalization. Ecological revitalization goes beyond simple environmental remediation to the in-depth reconstruction of the community of human and natural life. This requires not only maintaining the red line of cultivated land and protecting biodiversity, but also transforming ecological resources into development capital (Wen et al., 2018). For example, the exploration of the ecological compensation mechanism of carbon sink trading has made “lucid waters and lush mountains”① truly become quantifiable and tradable economic assets. Cultural revitalization focusing on the reshaping of the rural value system, it is necessary not only to excavate the wisdom crystallization of "harmony between man and nature" and "mutual help" in agricultural civilization, but also to realize the creative transformation of traditional culture and modern civilization through institutional vehicles such as the New Era Civilization Practice centre (Shen, 2020). For example, the combination of traditional village protection and intangible cultural heritage inheritance projects not only protects cultural genes but also cultivates new momentum for the integration of culture and tourism. Organizational revitalization builds a modern rural governance system through the "integration of three governances", which not only needs to strengthen the function of grassroots party organizations as "leading geese", but also needs to cultivate multiple governance entities such as township sage councils and farmers' cooperatives (Xie et al., 2021). For example, the innovation and promotion of Zhejiang's "Fengqiao Experience" is a typical practice of improving governance efficiency and resolving contradictions at the grassroots level through digital means. As a key support, talent revitalization is a special feature that runs through the whole process of the other four major revitalizations. Industrial upgrading requires new professional farmers, ecological protection depends on environmental technical talents, cultural inheritance is inseparable from local cultural workers, and organizational construction needs governance talents (Lei et al., 2022).

The core position of talent revitalization is reflected in three dimensions. 1. Talent is the key to solving the unequal exchange of urban and rural elements (Li et al., 2021) When cities continue to absorb rural young and middle-aged labour with high-quality public services, only through the innovation of talent mechanism of "internal education and external introduction" can the dilemma of net outflow of rural human capital be reversed. 2. Talent is the carrier of technological diffusion and institutional

①Central Committee of the Communist Party of China, State Council. (2015). Opinions on accelerating the construction of ecological civilization [EB/OL].[2015-04-25]. https://www.gov.cn/guowuyuan/2015-05/05/content_2857363.htm.

innovation. Whether it is the application of digital technology in agriculture or the reform of property rights systems such as the "separation of powers", leaders with a modern vision are needed to implement policies. 3. The quality of the talent team directly determines the sustainability of rural revitalization (Bian, 2019). At present, the phenomenon of "unfinished projects" and "bonsai projects" in various places is essentially the embodiment of the mismatch between talent ability and rural demand. Therefore, the central document particularly emphasizes the need to "unblock the channels of intelligence, technology, and management to the countryside", including the cultivation of local talents' "hematopoietic function", but also need to construct the "incentive mechanism for urban talents to enter the countryside" has formed a closed-loop system of "training→ introduction→ retaining → development"[①].

In the process of promoting the Rural Revitalization Strategy, its connotation shows significant dynamic evolution characteristics. With the comprehensive victory in the battle against poverty in 2020, the strategic focus has shifted from "ensuring the basics" to "promoting revitalization", and correspondingly, the demand for talent has expanded from foundational groups such as poverty alleviation officials and agricultural technicians to specialized professionals like rural planners and industrial brokers (Tang, 2021). This shift requires policy design to move beyond short-term project thinking to long-term investment mechanisms for building human capital. Only by placing talent revitalization at the core of the general requirement of "comprehensive revitalization" can we fully activate the endogenous power of rural revitalization, truly realize the grand blueprint of strong agriculture, beautiful countryside and rich farmers, and promote rural areas to move towards comprehensive prosperity and sustainable development in economic, social, cultural, ecological and

①Central Committee of the Communist Party of China, State Council. (2024). Opinions on learning and applying the experience of the "Thousand Villages Demonstration and Ten Thousand Villages Renovation" project to effectively and effectively promote the comprehensive revitalization of rural areas [EB/OL]. [2024-02-03]. https://www.gov.cn/zhengce/202402/content_6929934.htm.

other dimensions, so that the countryside can become a beautiful home to live and work in peace and contentment, and lay a solid foundation for the great rejuvenation of the Chinese nation.

2.1.2. The Connotation and Extension of Rural Talent Revitalization

As the core driving force of the Rural Revitalization Strategy, the definition of the connotation and extension of rural talent revitalization needs to break through the theoretical framework of traditional human resource management and be based on the dual context of urban-rural relationship reconstruction and rural social transformation. From the perspective of composition, rural talents are not a single group, but are composed of multi-level and multi-source composite subjects (Li, 2020). As a root-based force, local talents include not only agricultural experts and inheritors of intangible cultural heritage who have mastered traditional skills, but also modern agricultural operators who have obtained professional qualifications through the training of new professional farmers, who are irreplaceable in maintaining rural cultural genes and maintaining the stability of production systems (Zhang, 2022). Returnees show significant intergenerational differentiation, ranging from "urban returnees" who have completed capital accumulation in the city to start their own businesses, and retired cadres who have been led by the ties of nostalgia to participate in grassroots governance, making their cross-border experiences a natural medium for the transmission of urban and rural elements (Li, 2023). The introduction of talents as an exogenous increment includes not only technical experts embedded through systems such as "three branches and one support" and "science and technology correspondent", but also professional managers and rural planners brought by social capital to the countryside. The dynamic combination of the three types of talents, which essentially reconstructs the human capital structure as rural society transitions from a closed to an open system, directly influences the choice of rural development models through the balance among them.

In terms of function, talent cultivation needs to go beyond the limitations of traditional skills training and turn to the construction of a competency generation system (Ge, 2022). This requires the improvement of the targeted training mechanism of agriculture-related colleges, such as the "Rural Revitalization Master's Class" set up by Sun Yat-sen University, the implementation of the "academic + industry" dual tutor system, the establishment of a number of practical teaching bases, to help talents translate knowledge into practice in real-world scenarios. At present, most areas are still limited to project-based recruitment, lacking sustainable job supply and career development channels, and the "Rural Revitalization Specially Appointed Instructor" system piloted in Ningde City, Fujian Province, has effectively solved the problem of "difficulty in landing" high-level talents by setting up special positions that are not subject to establishment restrictions and supporting equity incentives (Wen, 2024). The key to talent retention lies in reconstructing the value of rural life, not only by improving material treatment, but also by equalizing public services and reshaping local cultural identity to enhance the sense of belonging (Li et al., 2021). Miluo City, Hunan Province has created a rural talent database, using big data technology to achieve intelligent matching between talent expertise and industrial needs, and increasing the efficiency of technological achievements by three times. The four functional dimensions constitute a closed-loop system, and its synergistic effect directly determines the implementation effect of talent revitalization, and if there is a shortcoming in a certain link, it may lead to system failure, such as the introduction of talents in some areas but neglecting to cultivate local strength, which ultimately leads to the embarrassing situation of "foreign monks are difficult to recite scriptures".

Compared with the concept of "rural human resources", rural talents place more emphasis on quality attributes and value creation capabilities (Luo et al., 2024). Rural human resources focus on quantitative statistics and demographic characteristics, covering all rural residents with the ability to work, while rural talents focus on high-quality human capital with professional skills, management ability or innovative qualities. For example, in Longsheng County, Guangxi, farmers who have mastered the unique skills of alpine tea cultivation are rated as "local experts", although their education level is only junior high school, but they have created the industrial value of varieties with unconventional yield per mu, and such practical talents are often omitted by the traditional human resources statistics system. For example, Chongqing's "Bayu Craftsman" program not only trains skills, but also promotes skill inheritance and product innovation through the establishment of rural skill master studios. This distinction is of special significance in the context of rural revitalization, as when the total amount of human resources shrinks due to the continuous outflow of the rural population, talent revitalization opens up a new development path by improving quality and efficiency.

Further analysis shows that the extension of rural talents has significant spatio-temporal dynamic characteristics, and its connotation is adaptively adjusted with the evolution of development stages and policy objectives. In the stage of poverty alleviation, the definition of talents focuses on short-term task-oriented groups, with village-based poverty alleviation cadres and agricultural technology extension workers as the core, and realizes the precise allocation of resources through policy guidance and project drive (Feng et al., 2025). Entering the stage of rural revitalization, with the demand for industrial digitalization and business diversification, talent extension urgently needs to be expanded to emerging professional fields, including digital agricultural technology experts, smart logistics engineers, rural cultural tourism planners, rural e-commerce operators and other professional groups (Abiri et al., 2023). This evolution demonstrates that the rural human capital structure undergoes a gradual, responsive progression. Consequently, policy design must be dynamically adaptive, establishing a feedback-driven mechanism that continuously aligns the catalog of needed talents with evolving industrial demands. At the same time, the concept of rural talents must break through the rigid constraints of the traditional household registration system. The "new township" groups who participate in rural construction should be included within the scope of policy coverage.Such groups include long-term resident artists, designers, social workers, and young entrepreneurs who have returned to their hometowns to start their own businesses, and although they do not have a local household registration, they are deeply involved in rural development through knowledge spillover, technology empowerment, and community building(Zhao, 2024). This inclusive definition not only reflects the "use-oriented" concept of talents, but also activates the "stock-increment" transformation channel of rural human capital through institutional innovation. From a theoretical perspective, the essence of rural talent revitalization is the systematic transformation of the development model, and its connotation has shifted from extensive growth relying on traditional factors such as land and labour to an endogenous driving model with human capital innovation as the core(Becker, 1964). The continuous broadening of this concept marks the in-depth reconstruction of rural value, from a single economic function to a multi-dimensional value complex such as ecology, culture, and governance. This transformation echoes the core concept of "skill-job" dynamic matching in the new human capital theory, and is also in line with the policy logic of "industry-talent" collabourative upgrading of the Rural Revitalization Strategy, and ultimately promotes the leapfrog development of rural areas from "factor depression" to "innovation highland"(Zu, 2024).

2.2. Rationale

2.2.1. Human Capital Theory

Theodore Schultz's theory of human capital provides guidance for the study of rural development. Its core contribution lies in transforming the homogeneous and static concept of labour in traditional economics into a dynamic form of capital, emphasizing that people's knowledge reserves, skill levels, and health status are not only factors involved in production activities, but also forms of capital that can be added through investment (Schultz, 1961). Through his systematic observation of economic evolution, Schultz reveals the limitations of physical capital investment and technological progress, and points out that the improvement of human capital is the key driving force for sustained productivity growth. His research subverts the single perspective of "factor determinism" and proposes that the deep contradiction of economic development is not a lack of resources, but a low-level equilibrium trap caused by insufficient investment in human capital. This equilibrium is manifested in chronic shortages in education, training, and health care, making it difficult for rural labour to break through the shackles of traditional empirical production models, resulting in intergenerational stagnation of knowledge updating and technology application. The formation mechanism of human capital presents a multidimensional path in Schultz's theoretical system. As a basic investment channel, education not only plays the role of knowledge transfer, but also cultivates the modern thinking of workers through the reshaping of cognitive frameworks (Schultz, 1971). This transformation of thinking enables workers to transcend the limitations of experience and develop sensitivity and adaptability to new technologies and markets. The training system focuses on the professional upgrading of the skill structure, transforms general knowledge into localized production capacity, and builds a bridge connecting macro technological progress and micro practical application. As a guaranteed dimension of human capital stock, health investment provides a physiological basis for the continuous accumulation of knowledge and skills by extending the effective labour cycle and improving labour efficiency (Heckman, 2000). The synergy of these three paths essentially builds a dynamic value-added system of human capital, and its operational efficiency directly determines the speed and quality of the transformation from traditional to modern.

In the specific context of rural development, the value-added effect of human capital is manifested through multiple mechanisms. The acceleration of technology diffusion stems from the mastery and innovation ability of rural talents. Rural talents with modern knowledge reserves can break through the cultural barriers and cognitive barriers in technology transplantation, and transform external innovation elements into practical solutions that adapt to the local ecology (Xu, 2000). This transformation involves not only the improvement of the level of technology, but also the creative integration of local knowledge to form a sustainable technology application ecology. The stimulation of industrial innovation capability relies on the "unbalanced response ability" generated by the accumulation of human capital. When rural workers break through the constraints of traditional production functions, their adaptability to external shocks such as market fluctuations and policy adjustments is significantly enhanced, and this dynamic adjustment ability becomes the internal driving force for the emergence of new forms of business and new models (Chen, 2025). Especially in the contemporary context of digital technology infiltrating rural areas, the quality of human capital directly determines the depth and breadth of digital transformation of traditional industries (Lin, 2025). As an implicit dimension of human capital appreciation, the improvement of governance efficiency is often achieved through institutional innovation and organizational change. Systematically educated rural governance subjects can break through the limitations of empirical decision-making and inject modern concepts such as participatory governance and digital management into grassroots practice(Li et al., 2022). The transformation of this governance model not only optimizes the efficiency of public resource allocation, but more importantly, builds an institutional framework that absorbs multiple subjects for collabourative co-governance, and provides structural support for the accumulation of rural social capital. In this process, human capital not only acts as a promoter of governance reform, but also feeds back the improvement of the governance system through capacity improvement, forming a virtuous circle of mutual construction of knowledge and institutions.

2.2.2. Regional Development Theory

Regional development theory provides an important perspective for analyzing the role of talent factors in the spatial pattern, in which the growth pole theory and the core periphery theory reveal the profound impact of talent flow on regional evolution from the perspective of a dynamic mechanism and structural relationship, respectively (Gennaioli et al., 2013).

The essence of the growth pole theory is to emphasize the dominance of the regional economy by the "pole core" with innovative ability in the process of uneven development (Bondaruk et al., 2013). In the rural context, talents, as carriers of knowledge, technology, and management capabilities, essentially constitute the core driving force of growth poles, and they form the agglomeration effect of production factors in a specific geographical space through entrepreneurial activities, technology diffusion, and organizational innovation. For example, rural youth with digital skills reconstruct the circulation chain of agricultural products through e-commerce platforms, and drive related industries such as warehousing and logistics, packaging and design to form industrial clusters within the rural area. The economies of scale generated by the initial talent agglomeration reduce the cost of entrepreneurship, and the spillover of innovation achievements further attracts external talents to move in, forming a positive feedback loop of "talent → industrial → opportunity". However, excessive polarization may lead to imbalances in intra-regional development, and in the absence of policy guidance, the diffusion effect of growth poles may lag behind the siphon effect, which will exacerbate the resource depletion in the periphery.

The core proposition of the core edge theory is that the asymmetric distribution of power and resources in the spatial system will form the dominant core area and the dependent edge area (Wang et al., 2025). The flow of talent between urban and rural areas essentially reflects this spatial power structure, with cities becoming core areas with high-quality public services, career opportunities, and innovation environments, which continue to absorb high-quality human capital from rural areas, while rural areas are reduced to marginal areas due to lagging infrastructure such as education and medical care, falling into a vicious circle of "brain drain→ stagnation of development→ and accelerated loss". This one-way flow not only weakens the endogenous power of rural areas, but also leads to the structural locking of urban-rural relations, with the urban core areas consolidating their dominant position through talent monopoly, while the trend of rural marginalization is difficult to reverse under the traditional path of industrialization. However, the penetration of digital technology is reconstructing the spatial logic of the core and the periphery, and the modes of remote work and online education have enabled some talents to access the urban economic system while retaining rural life, forming a new form of participation of "spatial periphery - functional core". This shift has broken the constraints of geographical proximity on innovation activities, making it possible for rural areas to form "anti-core" breakthroughs in specific fields through the construction of digital infrastructure and the empowerment of local talents.

The interweaving of these two theories reveals the duality of regional development. The growth pole theory emphasizes talent-driven disequilibrium breaking, while the core periphery theory warns of the systemic risk of spatial differentiation(Parr, 1999). In practice, the revitalization of rural talents needs to seek a dynamic balance between the two, not only to cultivate the growth pole of characteristic industries in the countryside to avoid overall marginalization, but also to prevent unipolar expansion through the convection mechanism of urban and rural factors. For example, the "enclave economy" model can combine the rural labour training system with the embedding of the urban industrial chain, which can not only take advantage of the technological spillover in the urban core area, but also avoid the complete detachment of rural talents from the local field. The deep significance of this spatial strategy lies in transforming the flow of talent from a zero-sum game to a value cycle, with the city becoming an incubator for the appreciation of rural human capital, and the countryside providing the city with a testing ground for technology application and a space for the reallocation of elements, and finally promoting the regional system from hierarchical domination to networked collabouration.

2.2.3. Theory of Urban-rural Integration Development

The theory of urban-rural integration development breaks through the traditional dual structure, and its policy logic is rooted in the deep reform of the market-oriented allocation of factors (Fang, 2022). For a long time, the flow of urban and rural factors has been subject to institutional barriers such as land, household registration, and social security, forming a distorted pattern of "one-way export of rural elements and difficulty for urban elements to go to the countryside" (Zhao et al., 2023). This asymmetrical flow not only exacerbates the hollowing out of the countryside, but also leads to diseconomies of scale caused by excessive urban agglomeration. Policy design for urban-rural integration therefore focuses on institutional improvement and institutional restructuring (Zhou et al., 2022). The reform of the land system activates the circulation of homestead use rights through the "separation of three rights"(namely the separation of land ownership, contract rights, and management rights), so that the rural space resources can be capitalized. The reform of the hukou system strips the binding of public services and hukou to create an institutional channel for the cross-regional flow of talents; Financial innovation transforms ecological resources in rural areas into tradable capital through tools such as "two-right" mortgage loans((i.e., loans using land management rights and contracted land use rights as collateral). These policies form a systematic system supply, the core of which lies in the construction of a rule system for the equal exchange of urban and rural elements, so that talents, capital and elements such as technology can achieve two-way convection based on market rules rather than administrative instructions, thereby unleashing combinatorial efficiency in spatial reconfiguration.

The mechanism of the talent factor in urban-rural integration is reflected in the dynamic process of "mobility→ transformation→ symbiosis". At the mobility level, as the carrier of knowledge and technology, the migration between urban and rural areas is essentially a cross-domain reorganization of innovation elements, with scientific researchers going to the countryside to promote the diffusion of agricultural technology, and rural craftsmen going to the city to promote the modernization and transformation of traditional crafts. This two-way flow breaks the closed nature of the urban and rural knowledge system and forms an innovative interface for heterogeneous knowledge collision (Tang et al., 2025). At the transformation level, talents transform generic knowledge into local knowledge through local practice, for example, planners integrate urban design concepts with rural ecological fabrics to create spatial forms with both modern functions and traditional aesthetics (Ji et al., 2023). This ability to transform knowledge makes urban and rural elements no longer a simple physical superposition, but a value reconstruction of chemical reactions. At the level of symbiosis, the flow of talent has given birth to a new type of urban-rural relationship network, urban makers and rural craftsmen have reshaped the division of labour in the industrial chain through collabourative production, and remote office groups have formed a composite spatial existence of "urban work and rural life", and this multi-subject interaction has built a functional community that transcends geographical boundaries (Cai et al., 2024).

The deeper mechanism lies in the redefinition of the value system of urban and rural areas by talent elements. When urban elites discover ecological and cultural values in rural practice, and when rural youth gain a premium on human capital through vocational education, the traditional hierarchical value evaluation criteria of urban and rural areas begin to dissolve. This cognitive revolution has promoted the reconstruction of the pricing mechanism of production factors. By establishing a unified value scale, it enables the fair exchange of urban and rural resources. This is exemplified by the marketization of the cultural value of intangible cultural heritage skills through IP operation, and more fundamentally, by making the ecological value of "lucid waters and lush mountains" explicit through mechanisms like carbon sink trading (Lin et al., 2025). In this process, rural talents play the dual role of value discoverers and value transformers, and their cross-border activities are essentially to establish a value dialogue channel between urban and rural elements. The effectiveness of this mechanism depends on the degree to which the institutional environment is tolerant of talent creativity, and when policies can protect the legitimate rights and interests of innovation and trial and error, talent elements can continue to activate the potential value of urban-rural integration, otherwise they may fall into an inefficient cycle of "flow without transformation and transformation without value-added" (Hu, 2025). Therefore, the theory of urban-rural integration development is not only a theory of spatial planning, but also a complex system theory involving multiple dimensions such as institutional economics and sociology (Wen, 2023).

2.3. Theoretical Model for Measuring the Level of Rural Talent Revitalization

2.3.1. Theoretical Model of an Evaluation System

The construction of a theoretical model for measuring the level of rural talent revitalization should be based on the holistic thinking of system theory, and the interaction relationship and dynamic evolution law of the internal elements of the complex system should be incorporated into the analytical framework. Systems theory emphasizes that a system is an organic whole composed of interrelated and interacting subsystems, and its functional emergence depends not only on the independent operation of each subsystem, but also on the energy exchange and information feedback mechanism across systems (Von Bertalanffy, 1950). In the context of rural talent revitalization, the three-dimensional logical framework of "input-output-influence" is essentially the transmission of the hierarchical structure and function of the system as the input end of the system, the rural talent guarantee activates the initial kinetic energy through the collabourative injection of institutional and material elements. The construction of rural talents corresponds to the transformation centre of the system, transforming the original elements into human capital increase; The effectiveness of rural talents reflects the release of the phased functions of the system and the overall reshaping of the economic and social environment, as shown in Figure 2.2. The theoretical legitimacy of this model lies in its complete mapping of the operation law of the complex adaptive system: from the input of factors to the transformation of achievements, the capital circulation of the economic subsystem, the relationship network of the social subsystem, and the ecological constraints of the environmental subsystem are always intertwined, and the nonlinear characteristics of the system can only be captured through multi-dimensional evaluation. The core basis for choosing the input-output-impact model is its intrinsic fit with system dynamics. System dynamics holds that the behaviour pattern of a system is determined by the interaction between accumulation variables (stock) and rate variables (flow). In the rural talent revitalization system, the rural talent guarantee corresponds to the rate variable, and changes the talent stock through flow input such as fund allocation, facility construction, and platform construction. As an accumulation variable, the scale and quality of rural talent construction constitute the core representation of the state of the system. The effectiveness of rural talents drives the optimization and upgrading of talent security through the results of talent development.

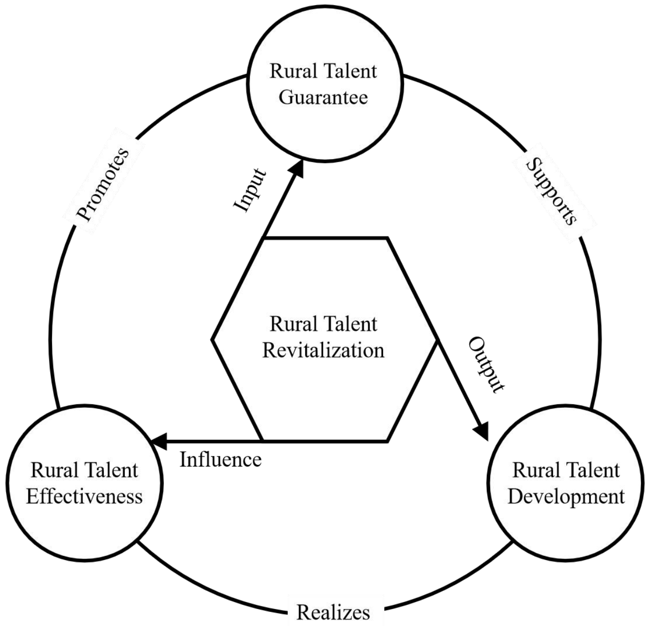

Figure 2.2: Logical framework of the evaluation system for rural talent revitalization

From the perspective of system hierarchy, the construction of the 3D framework echoes the spatial logic of Hall's 3D structural model (Sadjadi et al., 1980). The dimension of rural talent security corresponds to the resource dimension, focusing on the allocation of power and the allocation of factors in institutional design. The dimension of rural talent construction maps the time dimension and depicts the dynamic trajectory of human capital formation. Rural Talent effectiveness constitutes the knowledge dimension, and the value evaluation is completed from two levels: micro individual ability and macro system effectiveness. For example, simply measuring the number of talents may cover up the structural contradictions in policy implementation, and the coordinated observation of technology, production capacity and society can diagnose the system blockage of rural talents. The deeper theoretical support comes from the theory of dissipative structures. When the rural talent system introduces negative entropy flow through the input of resource elements, the original equilibrium state may be broken under the nonlinear interaction, and a new ordered structure may be formed. The "impact" dimension in the three-dimensional framework is a test of this orderliness, with production efficiency reflecting the enhancement of the self-organization ability of the industrial subsystem, innovation transformation reflecting the adaptability of the economic subsystem to the new structure, and rural improvement measuring the rationality of cost allocation of system change. The scientific nature of the model is also reflected in its inclusive design of feedback loops. The social and economic benefits generated by the effectiveness of rural talents will react to the guarantee of rural talents through the information feedback mechanism, forming a closed-loop adjustment of "resource input, implementation observation, effect evaluation, and strategy optimization" (Xu, 2021). This kind of feedback not only exists between the dimensions within the system, but also forms synergies across economic, social, and environmental subsystems.

2.3.2. Theoretical Support for Spatiotemporal Feature Analysis

The theoretical foundation of spatiotemporal feature analysis is deeply rooted in geography's essential understanding of spatial heterogeneity and temporal dynamics, and its core value lies in revealing the coupling law of "where to change" and "when to change" in the evolution of phenomena. The "everything is related, but the nearer is more correlated" concept proposed by the first law of geography is not a simple law of spatial attenuation, but a philosophical summary of the spatial dependence of complex systems (Tobler, 1970). In the study of rural talent revitalization, this is manifested as the spatial autocorrelation effect of talent revitalization, and the coordinated development pattern formed by policy imitation and information diffusion between adjacent regions makes the level of talent revitalization show spatial clustering characteristics. Heterogeneity stems from the unique combination of local factors, such as natural endowments and the institutional environment. Consequently, even neighboring villages may achieve divergent levels of talent revitalization, largely due to differences in their participation in specific policy pilots, such as the reform of the rural residential land system (Wang, 2022). This spatial heterogeneity can be effectively analyzed using a geographically weighted regression (GWR) model. For example, the GWR model can simultaneously quantify the global trend of talent agglomeration and diagnose the causes of outliers in specific areas (Li, 2023), such as mountainous villages, thereby revealing the "micro-rebellions under macro-laws".The dynamic evolution logic of time series analysis breaks through the limitations of static cross-sectional data, and regards the revitalization and development of rural talents as a stochastic process with memory and path dependence.

The deep enlightenment of the spatio-temporal differentiation theory of geography lies in the fact that the revitalization of rural talents is essentially a process of seeking dynamic equilibrium in the non-equilibrium spatio-temporal field. Spatial autocorrelation implies the possibility of regional synergy, and promotes knowledge spillover through the construction of talent flow corridors, but spatial heterogeneity warns of the risk of failure of the "one-size-fits-all" policy. The chaotic characteristics of time series require policy design to maintain moderate flexibility to cope with uncertainty, and it is necessary to establish an early warning mechanism to identify key turning points. The guiding value of this theoretical system for policy practice lies in the three-dimensional reconstruction of the cognitive framework. In terms of the spatial dimension, it is necessary to identify key geographical nodes and flow channels of talent development elements, and establish differentiated regional talent strategies. In terms of time, it is necessary to grasp the temporal rhythm of policy intervention and distinguish between the short-term stimulus and long-term mechanism of rural talent revitalization. In the dimension of spatio-temporal interaction, it is necessary to foresee the impact of spatial spillover effects and time delay to avoid the global imbalance caused by local optimization. At present, the theoretical frontier is shifting from deterministic spatio-temporal modeling to uncertainty management, and the entropy method is introduced to quantify the information gain and loss in spatiotemporal evolution, which provides a new tool for evaluating the spatiotemporal effectiveness of talent policy (Zhou, 2020). However, theoretical limitations also exist, and it is difficult for existing models to fully analyse the spatio-temporal effects of implicit elements such as cultural traditions, and the deep impact of rural social networks on talent flow still needs to be supplemented by sociological theory.

Chapter 3

Measurement of the Level of Rural Talent Revitalization

3.1. Construction of an Evaluation Index System

3.1.1. Basic Principles for the Construction of the Indicator System

The construction of the evaluation index system for rural talent revitalization should be based on the dual orientation of theoretical logic and practical needs, and follow the following core principles:

(1) The scientific and representative principle

Scientificity is the primary principle of the construction and selection of the indicator system, and the design of the index system for the revitalization of rural talents should be based on the theoretical connotation of the rural talent revitalization strategy, and closely focus on the policy objectives and the results of previous research. In the process of index selection, it is necessary not only to ensure the rigor of the theoretical framework, covering the core dimensions such as talent security, talent construction, and talent effectiveness, but also to refine the key characteristics through the selection of typical indicators. The principle of representativeness requires that the focus can reflect the core observation points of talent scale, structure, quality and role, avoid the redundancy of indicators caused by excessive pursuit of comprehensiveness, and take into account the influence of dynamic variables such as policy environment and regional differences, so as to ensure the explanatory power and adaptability of the indicator system.

(2) Systematic and hierarchical principles

The revitalization of rural talents is a complex system project, which involves many factors. Therefore, in the process of constructing the indicator system, it is important to uphold the system thinking, and it is necessary to reveal its internal logical relationship through the hierarchical structure. In the construction process, a three-level structure of "target layer-dimension layer-indicator layer" is adopted, and the core objectives are decomposed into dimensions such as talent security, talent construction, and talent efficiency from top to bottom, and are refined into observable specific indicators step by step. This tree-like structure not only ensures the integrity of the evaluation system, but also forms a logical closed loop through the affiliation between indicators, which can not only comprehensively present the development factors of talent revitalization, but also accurately locate the role path of each level, and provide an analytical framework for differentiated development.

(3) The quantifiable and objective principle

When carrying out evaluation research on rural talent revitalization, the practical value of evaluation research depends on the availability and verifiability of data. In the selection of indicators, it is necessary to give priority to the use of quantitative indicators with official statistical sources and unified standards, and reduce the interference of subjective judgement through quantitative representation. For some indicators that need to be indirectly measured, standardized data collection and processing methods need to be established to ensure the comparability of cross-regional and cross-time data. In the process of weight determination, objective weighting techniques such as the entropy method are used to reflect the importance of indicators through the information characteristics of the data itself, so as to avoid the potential impact of human subjective preference on the evaluation results to the greatest extent, and enhance the scientific credibility and policy reference value of the research conclusions (Li et al., 2025).

3.1.2. The Contents of the Evaluation Index System

To implement the overall task of China's Rural Revitalization Strategy and realize the expansion of the rural talent pool, the improvement of its quality, and the optimization of its structure, it is necessary to scientifically construct an evaluation index system for rural talent revitalization. Although there are great differences in rural areas in China, and there are differences in the development priorities and needs of different regions, a general index system framework can still provide a differentiated analysis of the level of rural talent revitalization in various regions. Based on theoretical analysis and existing literature research, this work constructs a multi-level sequential evaluation index system of "target layer-dimension layer-index layer" based on the common characteristics of rural talents and the connotation of talent revitalization in different dimensions. In the process of selecting specific indicators, the actual situation of China's rural talent revitalization was fully considered, the principles of scientificity, representativeness, systematization and measurability were followed, and the availability of data was ensured, and 21 specific indicators were finally determined, as shown in Table 3.1.

Table 3.1: Evaluation index system of rural talent revitalization level

Objective Layer	Dimension Layer	Indicator Layer	Specific Indicator
Rural Talent Revitalization	Talent Guarantee	A1 Infrastructure	A1.1 Rural Internet Penetration Rate (+)
			A1.2 Rural Mail Route Density (+)
			A1.3 Rural Park Green Space Coverage Rate (+)
		A2 Capital Investment	A2.1 Government Support Intensity for Agriculture (+)
			A2.2 Government Safeguard Intensity (+)
		A3 Cultivation Platform	A3.1 Industrial Platform Scale (+)
			A3.2 E-commerce Platform Scale (+)
	Talent Development	B1 Scale & Structure	B1.1 Scale of Agricultural Production and Management Talent (+)
			B1.2 Scale of Secondary and Tertiary Industries Talent (+)
			B1.3 Scale of Rural Public Service Talent (+)
			B1.4 Scale of Rural Governance Talent (+)
			B1.5 Scale of Agricultural and Rural Scientific and Technological Talent (+)
		B2 Quality Level	B2.1 Proportion of Rural Residents with Junior College Education or Above (+)
			B2.2 Per Capita Years of Education of Rural Residents (+)
	Talent Effectiveness	C1 Innovation & Transformation	C1.1 Per Capita Invention Patent Applications (+)
			C1.2 Total Power of Agricultural Machinery (+)
		C2 Production Efficiency	C2.1 Output Value of Agricultural Products (+)
			C2.2 Agricultural labour Productivity (+)
		C3 Rural Improvement	C3.1 Proportion of Migrant labourers Working Outside Township but Within County (+)
			C3.2 Per Capita Disposable Income of Rural Residents (+)
			C3.3 Engel's Coefficient of Rural Residents (-)

Note：(+) indicates a positive indicator,(-) indicates a negative indicator. Engel's Coefficient, which is the proportion of household income spent on food, is a widely used inverse measure of living standards (a lower value indicates a higher standard of living) (Beatty, 2011).

(1) Rural talent guarantee

By providing essential living guarantees, proper working conditions, and targeted policy support, local governments can help rural talents settle in confidently, mitigate brain drain, and ensure a stable talent pool to advance various rural development initiatives. When rural areas can provide comprehensive talent protection measures, they will become more attractive to external talents, so that more urban talents are willing to display their talents in rural areas, injecting new vitality and ideas into rural development (Yan et al., 2023). Under the condition that talents are fully guaranteed, they will have more confidence and motivation to tap their own potential, actively devote themselves to the work of rural construction, and give full play to their professional skills and wisdom. The "Opinions on Accelerating the Revitalization of Rural Talents" clearly points out that it is necessary to strengthen the measures to ensure the revitalization of rural talents, strengthen the investment guarantee for the revitalization of rural talents, increase investment in the development of rural human capital, build a platform for attracting and gathering talents in rural areas, build rural infrastructure and public service facilities, improve rural development conditions, improve the level of convenience of rural life, and attract urban and rural talents to stay in rural areas[①]. In this regard, this work comprehensively considers the three aspects of infrastructure(A1), capital investment(A2), and cultivation platform(A3), and reflects the rural talent security situation from seven aspects: rural Internet penetration rate(A1.1), rural per capita postal mileage(A1.2), rural per capita park green space(A1.3), government support for agriculture(A2.1), government guarantee(A2.2, such as specifical financial investment in talent development), industrial platform scale(A3.1), and e-commerce platform scale(A3.2), and the specific indicators are explained as follows:

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①General Office of the Central Committee of the Communist Party of China and General Office of the State Council. (2021). Opinions on Accelerating the Revitalization of Rural Talents [EB/OL]. [2021-02-23]. https://www.gov.cn/zhengce/2021-02/23/content_5588496.htm.

1) Interpretation of infrastructure indicators (A1)

The rural Internet penetration rate (A1.1, number of broadband access households/total number of rural households) reflects the degree of information technology penetration in rural areas, and the popularization of the Internet helps rural talents to obtain information, carry out e-commerce, and receive online education, and provides technical support for the development of rural talents. The mileage density of rural postal roads (A1.2, rural delivery lines (10,000/km)/village construction land area (10,000/ha)) reflects the coverage of postal services in rural areas, reflects the smoothness of logistics services such as mail and parcels in rural areas, and is of great significance for the exchange of rural talents, the circulation of materials and the transmission of information. The coverage rate of rural park green space (A1.3, i.e., public parks within and around villages) measures the quality of the ecological living environment. Such green spaces can enhance residents' quality of life, help attract and retain talent, and provide spaces for leisure and social interaction.

2) Explanation of capital investment indicators (A2)

The government's support for agriculture (A2.1), as measured by the ratio of agriculture, forestry and water expenditure to the total budget, directly affects the development of rural talents as the government's efforts to support agriculture can provide more agricultural subsidies, agricultural loans, and other policy support, promote the development of the agricultural industry, and attract more talented people to devote themselves to rural construction. The level of government protection (A2,2), as measured by the ratio of fiscal expenditure on social security and employment to the general budget, reflects the level of social security provided in rural areas. This safeguard ensures that rural talents can rely on the prevention of risks such as pension(old-age insurance), unemployment, and work-related injuries, so that they can maintain their basic living standards in the face of difficulties.

3) Interpretation of indicators for cultivation platforms (A3)

As a key component of the industrial platform, the scale of the national key leading enterprises of agricultural industrialization has a profound impact on the revitalization of rural talents. Large-scale leading enterprises tend to have a more complete industrial chain and can provide a variety of internship positions, so that agricultural production and management talents can accumulate experience in various processes. At the same time, with strong resource integration capabilities, leading enterprises can link upstream and downstream industries, absorb rural secondary and tertiary industry development talents, and broaden the career path of rural talents. The number of "Taobao villages" (rural communities where e-commerce, particularly on the Taobao platform, drives the local economy) is one of the manifestations of the scale of e-commerce platforms in rural areas. When the scale of e-commerce platforms expands, more rural areas are radiated by it, giving birth to a large amount of e-commerce. Online stores have become a "training ground" for rural e-commerce talents, and young people can quickly grow from novices in online store operation to professionals who are proficient in online marketing, customer service, logistics and distribution coordination. Therefore, this study measures the scale of industrial platforms and e-commerce platforms through the number of national key leading enterprises in agricultural industrialization (A3.1) and the number of "Taobao villages" (A3.2), and takes into account the differences in different regions, and performs natural logarithmic processing of the data.

(2) Rural talent construction

Rural talent construction is a key part of the Rural Revitalization Strategy, and scale structure and quality level are the two core dimensions to measure the effectiveness of talent construction, which complement each other and develop in tandem to inject strong impetus into the prosperity of rural areas. The Plan for the Comprehensive Revitalization of Rural Areas (2024-2027) clearly states that it is necessary to strengthen the rural talent team[①]. The scale structure of rural talents covers the distribution and proportion of talents in different fields and at different levels. For a long time, there has been a shortage of rural talent and an imbalance in its distribution. There is a relative surplus of talents in the traditional agricultural field, while there is a shortage of talents in the fields of rural secondary and tertiary industries, rural public services, and social governance, resulting in difficulties in the integration of rural industries and lagging behind in the development of social undertakings. The quality level of rural talents includes professional knowledge, skills, education and other aspects. With the continuous improvement of the quality level of rural talent, the role of talent in rural construction will be brought into full play. Through the construction of rural talents, we will eventually cultivate a "three rural" work team that understands agriculture, loves the countryside and loves farmers, and provides a strong foundation for rural revitalization talent guarantee and intellectual support. In this regard, this work constructs seven indicators to reflect the construction of rural talents from the two dimensions of scale structure (B1) and quality level (B2), including the scale of agricultural production and management talents (B1.1), the scale of rural secondary and tertiary industry development talents (B1.2), the scale of rural public service talents (B1.3), the scale of rural governance talents (B1.4), the scale of agricultural and rural science and technology talents(B1.5), the proportion of rural residents with college degree or above (B2.1), and the per capita years of education of rural residents (B2.2). The specific indicators are explained as follows:

1) Explanation of scale structure indicators (B1)

Agricultural production and management talents (B1.1) are an important force for rural revitalization, including leaders of professional farmer cooperatives and family farmers. Sufficient personnel for agricultural production and management can ensure

①Central Committee of the Communist Party of China, State Council. (2025). Comprehensive rural revitalization plan (2024-2027) [EB/OL]. [2025-01-23]. https://www.gov.cn/zhengce/202501/content_7000493.htm.

the stable development of the agricultural industry and improve the efficiency of agricultural production. With the transformation and upgrading of rural industries, the demand for talents in rural secondary and tertiary industries is increasing (B1.2), and expanding the scale of talents in rural secondary and tertiary industries can promote the diversified development of rural industries and increase farmers' incomes. Rural public service talents (B1.3) include rural teachers, rural doctors, and rural planning and construction workers. They provide rural residents with public services such as education, medical care, and culture, which is an important guarantee for rural revitalization. Rural governance talents (B1.4) are the key force of rural revitalization, and rural governance talents are inseparable from improving the level of rural governance and promoting the harmony and stability of rural society. Agricultural and rural scientific and technological personnel(B1.5) are an important force in promoting rural scientific and technological innovation, improving agricultural scientific and technological innovation capabilities, providing technical support to farmers, and promoting the modernization and development of the agricultural industry. Based on the availability, validity, and comparability of the data, representative groups were selected for measurement of the above five indicators, as shown in Table 3.2.

Table 3.2: Explanation and explanation of rural scale structure indicators

Indicator	Indicator Explanation
Scale of Agricultural Production and Management Talent (B1.1)	(Number of Family Farm Operators + Number of Leaders of Farmer Cooperatives) / Rural Population
Scale of Secondary and Tertiary Industries Talent (B1.2)	Employment Number in Rural Private Enterprises / Rural Population
Scale of Rural Public Service Talent (B1.3)	(Number of Rural Teachers + Number of Rural Health Personnel + Number of Rural Construction Personnel) / Rural Population
Scale of Rural Governance Talent (B1.4)	Number of Participants in the "Three Supports and One Assistance" Program / Rural Population
Scale of Agricultural and Rural S&T Talent (B1.5)	Number of Personnel Engaged in Agricultural S&T Activities / Rural Population

2) Explanation of quality level indicators (B2)

The proportion of rural residents with a college degree or above (the number of rural residents with a college degree or above/rural population) reflects the overall education level of rural areas(B2.1). A high proportion means that the countryside can have more highly educated talent groups. These talents often have more solid professional knowledge, stronger learning ability and broader vision, and can introduce advanced concepts and cutting-edge technologies into the countryside, so as to effectively promote the development of rural industries, cultural construction, social governance and other aspects of progress, inject a steady stream of intellectual power into rural revitalization, and help rural areas in modern agriculture and rural e-commerce. Breakthroughs and development have been achieved in emerging fields such as rural tourism, which has fundamentally improved the ability of rural self-development and narrowed the gap between urban and rural development. The average number of years of schooling per rural resident (∑(number of rural residents at each level of education×number of years of schooling at the corresponding level of education)/number of rural population) measures the average level of education of rural residents as a whole, covering all levels of education, from basic education to tertiary education(B2.2). Extending the number of years of schooling per capita is crucial to improve the literacy of rural residents across the board. The improvement of cultural quality can enable rural residents to better understand new knowledge and master new skills, stimulate innovative thinking and creativity, and lay a solid foundation for the growth and development of rural talents.

(3) Effectiveness of rural talents

Giving full play to the effectiveness of talents, contributing to rural revitalization, and realizing the reform of agricultural and rural modernization are the ultimate goals of rural talent revitalization. The "14th Five-Year Plan for the Construction and Development of Agricultural and Rural Talent Teams" emphasizes the need to make the role of rural talent teams more fully utilized[①]. Rural talents not only provide key technical support for food security guarantee, the optimization of the agricultural product supply system, and the improvement of agricultural quality and efficiency, but also play a strategic leading role in promoting the innovation of the rural land system, the modernization of the rural governance system, and the construction of harmonious and beautiful villages. Their value runs through the whole process of changes in agricultural production efficiency, the reconstruction of the industrial system, and the transformation of rural society. The exertion of talent effectiveness is an important criterion for measuring the achievements of rural talent revitalization. Only when rural talents can truly play a role in rural revitalization and achieve tangible results can it be said that the work of rural talent revitalization has been successful. At the same time, the full exertion of talent effectiveness can drive the development of the rural economy, social progress, and ecological improvement, thus attracting more talents to engage in rural construction and forming a virtuous cycle of mutual promotion between rural development and talent revitalization. In this regard, starting from the three dimensions of innovation transformation(C1), production efficiency improvement(C2), and rural improvement(C3), this work constructs seven indicators, including the average number of patent applications per capita(C1.1), the total mechanical power per mu(C1.2), the output value of agricultural products per mu(C2.1), agricultural labour productivity(C2.2), the proportion of rural migrant workers within the county but outside the township(C3.1), the per capita disposable income of rural residents(C3.2), and the Engel coefficient of rural residents(C3.3, the proportion of food expenditure in total consumption, an inverse measure of living standard), to reflect the effectiveness of rural talents. The specific explanations of the indicators are as follows:

①Ministry of Agriculture and Rural Affairs. (2021). The 14th Five-Year Plan for the Construction and Development of Agricultural and Rural Talent Teams [EB/OL]. [2021-12-17]. https://www.moa.gov.cn/nybgb/2022/202202/202204/t20220401 6395088.htm.

1) Interpretation of innovation transformation indicators(C1)

The innovation ability of rural talents is reflected through the per capita number of invention patent applications (C1.1, the number of agricultural invention patent applications in the current year / rural population), manifested in the effectiveness of promoting rural scientific and technological innovation and facilitating the transformation and upgrading of the agricultural industry. The mechanical power per mu (C1.2, total power of agricultural machinery (kW) / area of crops (mu)) represents the level of mechanization of agricultural production, reflects the efficiency of agricultural production and a high value reduces the labour intensity of farmers and creates better production conditions for rural talents.

2) Interpretation of production efficiency indicators(C2)

The average output value of agricultural products per mu (C2.1, output value of agricultural products (100 million yuan)/area of crops (mu)) measures agricultural production benefits. Increasing the output value of agricultural products per mu can increase peasants' incomes and promote the development of agricultural industry. The agricultural labour productivity rate (C2.2, agricultural added value (10,000 yuan)/the number of employed people) reflects the efficiency of agricultural production, and improving the agricultural labour productivity rate can reduce the cost of agricultural production, improve the competitiveness of agriculture, and create more development opportunities for rural talents.

3) Interpretation of rural improvement indicators(C3)

The proportion of migrant labour working outside township but within counties (C3.1, the number of migrant workers outside the township/the total number of migrant workers) reflects the mobility of rural labour at the local level. This emloyment mode promotes employment opportunities close to home, helps reduce the phenomenon of rural hollowing, and provide human resource support for rural revitalization. The per capita disposable income of rural residents (C3.2, direct data from the statistical yearbook) measures the standard of living of rural residents. The

Engel coefficient(C3.3) is calculated as the share of food expenditure in total consumption, reflecting the consumption structure and is a mature inverse measure of affluence. A lower coefficient indicates a higher standard of living.

3.2. Data Description and Measurement Methods

3.2.1. Data Sources and Processing

In this study, 31 provincial-level administrative regions in the Chinese mainland from 2008 to 2022 (data from Hong Kong, Macao and Taiwan are not included in the scope of the investigation) were used as investigation samples to construct a panel dataset covering 15 years. The principles of accuracy and credibility of data collection are mainly derived from 11 authoritative yearbooks compiled by the Chinese National Bureau of Statistics, including the China Statistical Yearbook[①], China Social Statistical Yearbook (available through Statistical Publishing House), China Rural Statistical Yearbook[②], China Rural Management Statistical Yearbook (obtained through the China National Knowledge Infrastructure (CNKI) Statistical Yearbook database), China Rural Cooperative Economy Statistical Yearbook (obtained through CNKI Statistical Yearbook database), China Science and Technology Statistical Yearboo (obtained through CNKI Statistical Yearbook database), China Health Statistical Yearbook (obtained through CNKI Statistical Yearbook database), China Education Statistical Yearbook[③], China Rural Policy and Reform Statistical Yearbook (obtained through CNKI Statistical Yearbook database), China Environmental Statistical Yearbook[④], and China Urban and Rural Construction Statistical Yearbook compiled by the National Bureau of Statistics (2009-2023 volume). At the same time,

① https://data.stats.gov.cn/english/publish.htm

② http://60.16.24.131/CSYDMirror/area/yearbook/Single/N2024010048?z=D30

③ https://so.moe.gov.cn/s?siteCode=bm05000001&tab=all&qt=%E4%B8%AD%E5%9B%BD%E6%95%99%E8%82%B2%E7%BB%9F%E8%AE%A1%E5%B9%B4%E9%89%B4

④ https://www.mee.gov.cn/hjzl/sthjzk/sthjtjnb/

the official statistical yearbooks and government statistical bulletins released by provincial statistical institutions were also referred to, including 31 provincial statistical yearbooks (which can be obtained through the official websites of local statistics bureaus)①, annual statistical bulletins on national economic and social development, as well as special statistical data released by government departments (released on the official website by the National Bureau of Statistics and local statistical bureaus from February to March every year, covering the main indicators of economic and social development in the previous year) . All data are derived from the original statistical data officially released, ensuring the authority and reliability of the data.

For data gaps in particular fields, mixed data is used for measurement. For example, the number of "three branches and one support" personnel in 2008 is equal to the sum of the number of recruits in 2006 and 2007, and the number of recruits in "three branches and one support" comes from the provincial recruitment announcement in that year. The number of "Taobao Villages" comes from the official directory of the "China Taobao Village Research Report" of the Alibaba Research Institute (See Appendix II for details), and the criteria for recognition are administrative villages (excluding neighborhood committees) with annual e-commerce sales of 10 million yuan or more; If the number of active online stores reaches 100 or more, or the number of active online stores reaches 10% or more of the number of households, it can be recognized as a "Taobao Village". According to data released by the Ministry of Agriculture and Rural Affairs, as of the 13th Five-Year Plan, there were 5.49 million family farmers and leaders of farmer cooperatives in China. In line with the number of family farms and farmer cooperatives. Recording agricultural science and technology personnel, referring to the industrial suitability

① The website addresses of some major provincial and municipal statistical yearbooks:
https://nj.tjj.beijing.gov.cn/nj/main/2024-tjnj/zk/indexch.htm
https://tjj.sh.gov.cn/tjnj/index.html
http://tjj.gz.gov.cn/attachment/7/7730/7730891/10010720.pdf

adjustment method proposed by Zhong (2023), adopts the industry conversion coefficient of "full-time equivalent of R&D personnel×(gross output value of agriculture, forestry, animal husbandry and fishery/gross regional product)".

For the missing values, they are filled according to the missing situation. Before 2018, there was a lack of data on multiple indicators in Tibet, and the combination of imputation and time series analysis based on similar regions is adopted. The specific steps are as follows: Select provinces (Xinjiang, Qinghai, Sichuan, and Yunnan) that are similar to Tibet in terms of geography, economy, and society, and use the average annual growth rate of these provinces to calculate the average annual growth rate. For some provinces, a small number of data are missing in individual years, and the mean value is used to fill in, that is, the average value of the previous year and the following year. For the missing data of all provinces in a certain year, the linear interpolation method is used to fill in the missing data. This method estimates the missing values based on the linear relationship between known data points, and is suitable for scenarios where data changes linearly. If the missing data year is 2022, linear interpolation cannot be applied because 2022 is the end point of the dataset (2008-2022), so regression imputation is used. This method improves accuracy by predicting missing values using regression models created by other available variables.

3.2.2. Measurement Methods

Based on the Multiple Criteria Decision Making (MCDM) framework, this study constructs an evaluation model for rural talent revitalization. The MCDM framework is a systematic approach to decision analysis that aims to help decision-makers make more comprehensive and balanced decisions in the face of multiple conflicting criteria or objectives (Taherdoost et al., 2023). The framework helps decision-makers find the best or most satisfactory solution in complex decision-making situations by considering multiple criteria together. In practice, MCDM frameworks typically begin with a clear decision-making objective, identify all criteria or criteria that influence decision-making, define quantifiable attributes or indicators for each criterion, and collect data related to those attributes. They determine the importance weight of each criterion and score each attribute, multiplying the score of each attribute by its weight to obtain a composite score for each option. Finally, all alternatives are ranked based on these composite scores to identify the optimal choice.

In the comprehensive evaluation of the revitalization level of rural talents, it is crucial to determine the weight of each index. At present, the academic community mainly adopts two methods: subjective empowerment and objective empowerment. In terms of subjective empowerment, the analytic hierarchy process (AHP) is typical, which relies on the experience and judgement of experts and is susceptible to individual preferences and may lead to systemic bias (Canco et al., 2021). Therefore, research in recent years has tended to use objective weighting methods, such as the Entropy method, which can effectively avoid the bias caused by experts' subjective judgements by reflecting the dispersion of indicators through information entropy (Kumar et al., 2021). In addition, Principal Components Analysis (PCA) is also a commonly used objective weighting method by reducing the dimensionality of data, extracting principal components, and determining weights based on the variance contribution rate (Liu et al., 2023). In order to further improve the robustness of the model, the comprehensive weighting methods came into being, which combines the advantages of the subjective and objective weighting method, which not only considers the objectivity of the data, but also takes into account the empirical judgement of experts, making the weighting determination more scientific and reasonable (Al-Abadi et al., 2025).

In terms of the selection of comprehensive evaluation methods, the commonly used methods in academia include Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), Grayscale Relational Analysis (GRA), Fuzzy Comprehensive Evaluation, and Data Envelopment Analysis (DEA). The TOPSIS method ranks the evaluation objects by calculating the distance between them and the ideal and negative ideal solutions to determine the optimal solution (Chakraborty, 2022). The core idea of this approach is that the optimal solution should be closest to the ideal solution (a hypothetical alternative that scores the best value on every criterion) and at the same time furthest from the negative ideal solution (which scores the worst on every criterion). The advantage of the superior and inferior solution distance method is that it is intuitive and easy to understand, and can effectively deal with multi-index decision-making problems. Grey Relational analysis is mainly used to analyze the degree of correlation among factors in the system (Jana et al., 2021). This method assesses the degree of association between each scheme and the ideal scheme by calculating the grey regression coefficients of the reference sequence and the comparison sequence. The advantage of the grey correlation analysis method lies in its ability to handle small samples and incomplete information, and it is suitable for research scenarios where data is relatively scarce. Based on the theory of fuzzy mathematics, the fuzzy comprehensive evaluation method is suitable for dealing with the problem of ambiguity and uncertainty of evaluation indicators, and converts qualitative indicators into quantitative data by constructing ambiguous membership functions, and conducts comprehensive evaluation in combination with weights (Wu et al., 2021). Data envelopment analysis is a non-parametric efficiency evaluation method, which is mainly used to evaluate the relative efficiency of multi-input and multi-output systems, and calculates the distance between each decision-making unit and the ideal output by constructing the ideal output of production, so as to evaluate its efficiency level (Zheng, 2021).

Comprehensively comparing the characteristics of the existing methods, this study finally selected the entropy weight-TOPSIS model commonly used by scholars for measurement (Ashraf et al., 2025). The model combines the advantages of the entropy method and the TOPSIS method, forms a multi-dimensional evaluation space by constructing positive and negative ideal solutions, and uses the weighted Euclidean distance to calculate the proximity of each evaluated region(i.e., each provincial-level unit) to the ideal solution, so as to realize multi-dimensional and multi-object non-parametric sorting. The advantage of the entropy-weight-TOPSIS model is that it can effectively avoid the interference of subjective judgement and achieve objective ranking through data-driven results. Dimensional differences in compatible heterogeneity indicators allow indicators of different dimensions to be compared under the same framework. The results of the evaluation are fully ordinally comparable, providing a clear picture of the strengths and weaknesses of different regions. The specific implementation process is as follows:

Step 1: Build a raw data matrix.

$$X = [x_{ij}]_{m\times n} . \quad (3.1)$$

In Eq.(3.1), x_{ij} represents the j^{th} evaluation index for the i^{th} evaluation unit ($i = 1,2,3,\ldots,m$; $j = 1,2,3,\ldots,n$). m=31 and n=21 represent 31 provincial talent revitalization evaluation units and 21 evaluation indicators, respectively.

Step 2: Normalize the data. The original data of positive and negative indicators of rural talent revitalization evaluation were standardized by using the range standardization method most commonly used by relevant researchers, so as to eliminate the influence of the index dimension and make the data comparable.

For positive indicators: $$x_{ij}^{'} = \frac{x_{ij}-min(x_j)}{max(x_j)-min(x_j)} + \Delta, \quad (3.2)$$

For negative indicators: $$x_{ij}^{'} = \frac{max(x_j)-x_{ij}}{max(x_j)-min(x_j)} + \Delta. \quad (3.3)$$

In equation (3.2) and (3.3), $max\,(x_j)$ and $min\,(x_j)$ is expressed as the maximum and minimum values of all provinces in the j^{th} index, respectively, and $\Delta = 0.0001$ is the translation constant, and the normalized data is translated to avoid the interference of zero values, resulting in the inability to perform logarithmic calculations.

Step 3: Calculate the weight of the indicator. Calculate the proportion of $x_{ij}^{'}$, the j^{th} rural talent revitalization evaluation indicator for the ith evaluation object p_{ij}.

$$p_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{m} x_{ij}^{'}} . \quad (3.4)$$

Step 4: Calculate the information entropy of the j^{th} indicator.

$$e_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij} \ . \tag{3.5}$$

In Equations (3.5), $k = \frac{1}{\ln(mn)}$ and $k > 0$, which ensures $e_j \geq 0$. $(1 - e_i)$ represents the redundancy of the information entropy of an indicator; a larger value of it indicates a greater weight of the indicator.

Step 5: Calculate the weight of the first indicator.

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \ . \tag{3.6}$$

Step 6: Calculate the weighted matrix V.

$$\mathrm{V} = [\mathrm{v_{ij}}]_{\mathrm{m \times n}} = [w_j \cdot x_{ij}^{'}]_{\mathrm{m \times n}} \ . \tag{3.7}$$

Step 7: Determine the positive ideal solution V_j^+ and the negative ideal solution V_j^-.

$$V_j^+ = \max_i (v_{ij}), \tag{3.8}$$

$$V_j^- = \min_i (v_{ij}). \tag{3.9}$$

Step 8: Calculate the Euclidean distance from each evaluation object to the positive and negative ideal solution D_i^+ and D_i^-.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2} \ , \tag{3.10}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \ . \tag{3.11}$$

Step 9: Calculate the Proximity Index (Composite Score Level)

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \ . \tag{3.12}$$

In Equation (3.12), $C_i \in [0,1]$. The larger the value of C_i, the higher the comprehensive level of rural talent revitalization in the province; the smaller the value of C_i, the lower the comprehensive level of rural talent revitalization in the province.

3.3. Analysis of the Results of Rural Talent Revitalization

3.3.1. Weight Analysis of Indicators of Rural Talent Revitalization Level

The entropy method was used to weight the level index of rural talent revitalization, and the results are shown in Table 3.3. Through the analysis of the weight ratio of the evaluation indicators at each level, it is found that in the ranking of the importance of the dimension layer, the construction of rural talents ranks first, accounting for 36.63%, followed by the guarantee of rural talents, accounting for 32.84%, and finally the rural talent efficiency, accounting for 30.44%. The results show that the core of the revitalization of rural talents lies in the construction and cultivation of talents, followed by the guarantee conditions for talent development, and finally the play of talent efficiency.

Table 3.3: Weights of the evaluation system for rural talent revitalization

Objective Layer	Dimension Layer	Weight	Specific Indicator	Weight
Rural Talent Revitalization	Rural Talent Guarantee	0.3284	A1.1 Rural Internet Penetration Rate	0.0676
			A1.2 Rural Mail Route Density	0.0321
			A1.3 Rural Park Green Space Coverage Rate	0.0503
			A2.1 Government Support Intensity for Agriculture	0.0312
			A2.2 Government Safeguard Intensity	0.0254
			A3.1 Industrial Platform Scale	0.0305
			A3.2 E-commerce Platform Scale	0.0992
	Rural Talent Development	0.3663	B1.1 Scale of Agricultural Production and Management Talent	0.0625
			B1.2 Scale of Secondary and Tertiary Industries Talent	0.1068
			B1.3 Scale of Rural Public Service Talent	0.0241
			B1.4 Scale of Rural Governance Talent	0.0588
			B1.5 Scale of Agricultural and Rural S&T Talent	0.0444
			B2.1 Proportion of Rural Residents with Junior College Education or Above	0.0465
			B2.2 Per Capita Years of Education of Rural Residents	0.0225
	Rural Talent Effectiveness	0.3044	C1.1 Per Capita Invention Patent Applications	0.0885
			C1.2 Total Power of Agricultural Machinery	0.0364
			C2.1 Output Value of Agricultural Products	0.0462
			C2.2 Agricultural labour Productivity	0.0420
			C3.1 Proportion of Migrant labourers Working Outside Township but Within County	0.0433
			C3.2 Per Capita Disposable Income of Rural Residents	0.0247
			C3.3 Engel's Coefficient of Rural Residents	0.0159

At the level of specific indicators, the weight of the rural secondary and tertiary industry talent scale index in the dimension of rural talent construction is the highest, reaching 10.68%, highlighting the key role of rural secondary and tertiary industry talents in promoting rural economic development. The weight of the scale index of e-commerce platforms in rural talent guarantee is 9.92%, indicating that e-commerce platforms, as an important carrier of rural talents' entrepreneurship and employment, have a significant supporting role in the revitalization of rural talents. The per capita weight of invention patent applications in the rural talent efficiency index is 8.85%, reflecting the importance of rural talents' innovation ability, especially in promoting the transformation and upgrading of rural industries and scientific and technological progress.

3.3.2. Estimation Results and Analysis of the Level of Rural Talent Revitalization in China

Further, this study calculates the national rural talent revitalization level index and its change trend from 2008 to 2022, and the results are shown in Figure 3.1. As can be seen from the figure, the overall level of rural talent revitalization in China has shown a steady upward trend, with the index value increasing from 0.1357 in 2008 to 0.3814 in 2022, an increase of 181%, with an average annual growth rate of 7.66%. This remarkable growth trend shows that the Chinese government attaches great importance to the development and revitalization of rural talents, and has introduced a series of targeted policies during the research period, such as talent introduction plans and innovation and entrepreneurship support measures, which have successfully attracted more talents to devote themselves to rural construction. These policies have not only optimized the structure of rural talents, but also injected strong impetus into rural revitalization and promoted the comprehensive development of rural economy and society.

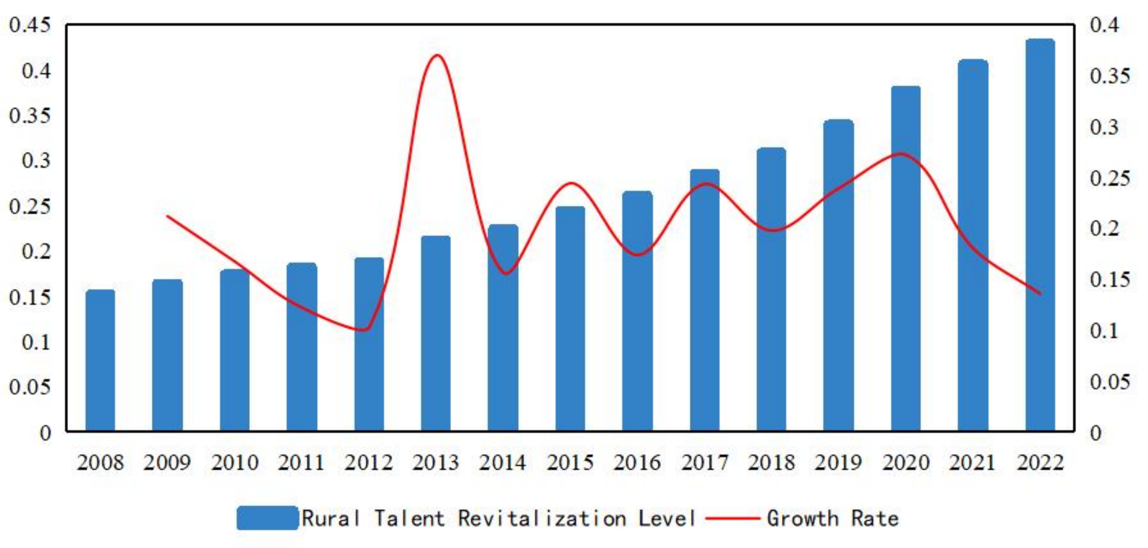

Figure 3.1: Trend of rural talent revitalization from 2008 to 2022

From the perspective of growth rate changes, the development of rural talent revitalization level can be divided into three stages. From 2008 to 2012, the level of rural talent revitalization was in a slow climbing stage, with the growth rate fluctuating between 11.52% and 23.81%, and declining year by year. This period coincided with the acceleration of China's urbanization process, the phenomenon of rural labour outflow was more prominent, and the policy focus was more focused on agricultural modernization and rural infrastructure construction, and the development of rural talents had not yet become a core issue. From 2013 to 2017, with the in-depth implementation of the Outline of the National Medium- and Long-Term Talent Development Plan (2010-2020), rural talents gradually received attention, and the growth rate increased significantly①. For example, the 2015 "Opinions on Supporting Migrant Workers and Other Personnel to Return to their Hometowns and Start Businesses" explicitly supported migrant workers and other groups to return to their

①Central Committee of the Communist Party of China and the State Council. (2010). Outline of the national medium- and long-term talent development plan (2010-2020) [EB/OL]. [2010-06-06]. https://www.gov.cn/jrzg/2010-06/06/content_1621708.htm.

hometowns and start businesses[①], and the 2016 "Opinions on Deepening the Reform of the Talent Development System and Mechanism" issued by the Central Committee of the Communist Party of China (CPC) pointed out that the flow of talents to difficult and remote areas and grassroots frontlines should be promoted.[②] At this stage, the rise of emerging industries such as rural e-commerce, leisure agriculture and rural tourism has attracted a large number of entrepreneurial talents and professional and technical talents who have returned to their hometowns, injecting new momentum into the revitalization of rural talents. From 2018 to 2022, although the full implementation of the Rural Revitalization Strategy has brought the revitalization of rural talents into the fast lane, the growth rate has slowed down compared with the previous five years. This phenomenon may be attributed to multiple factors, such as the gradual stabilization of policy effects, the complexity of rural industrial restructuring, and the long-term existence of the resource gap between urban and rural areas. Despite this, the overall level of rural talent revitalization has remained steadily improving, and the pattern of coordinated efforts of policies, funds and industries has been preliminary. It has laid a solid foundation for the continuous promotion of rural talent revitalization. In the future, in order to further improve the revitalization level of rural talents, it is necessary to continue to optimize the policy support system, increase capital investment in rural industrial development, and promote the balanced allocation of urban and rural resources, so as to attract more high-quality talents to take root in the countryside and inject lasting impetus into rural revitalization.

From different dimensions, from 2008 to 2022, the development level of rural talent security, rural talent construction, and rural talent efficiency showed a

①General Office of the State Council. (2015). Opinions on supporting migrant workers to return to their hometowns and start businesses [EB/OL]. [2015-06-21]. https://www.gov.cn/zhengce/content/2015-06/21/content_9960.htm.

②Central Committee of the Communist Party of China. (2016). Opinions on deepening the reform of the system and mechanism of talent development [EB/OL]. [2016-03-21]. https://www.gov.cn/xinwen/2016-03/21/content_5056113.htm.

significant upward trend, with an increase rate of 2.24 times, 2.43 times, and 2.05 times, respectively, with an average annual growth rate of 8.76%, 9.19%, and 8.28%, respectively. Through the comparison of dimensions, it is found that from 2008 to 2022, the three dimensions of rural talent revitalization have risen alternately, showing different development trends. Among them, the rapid growth of rural talent construction is particularly prominent, reflecting the remarkable effect of policy support on the cultivation and introduction of rural talents.

From 2008 to 2012, the efficiency of rural talents was leading, but the basic guarantee was insufficient. As shown in Figure 3.2, at this stage, the level of rural talent security increased from 0.0439 to 0.0510, with an average annual growth rate of 3.83% and an increase of 16.24%. The level of rural talent construction increased from 0.03925 to 0.0561, with an average annual growth rate of 9.37% and an increase of 43.10%. The level of rural talent efficiency increased from 0.0402 to 0.0598, with an average annual growth rate of 10.46% and an increase of 48.87%. During this period, the development momentum of rural talent efficiency was strong, and the growth rate was noticeably higher than the level of rural talent guarantee and construction, resulting in the evolution of the development pattern from "rural talent security> rural talent construction> rural talent efficiency" to "rural talent efficiency > rural talent construction> rural Talent Guarantee". However, this talent-driven dynamic is not self-sustaining. Securing a basic level of support for talents is fundamental, as a stable talent workforceis essential for leveraging their full impact. Inadequate incentives for rural talent retention can trigger brain drain, block new talent inflow, and jeopardize the long-term maintenance of the rural talent base, consequently hindering sustained productivity gains. This reveals that revitalizing rural talent requires not only boosting short-term outcomes but also establishing robust long-term mechanisms to secure a stable and sustainable talent supply.

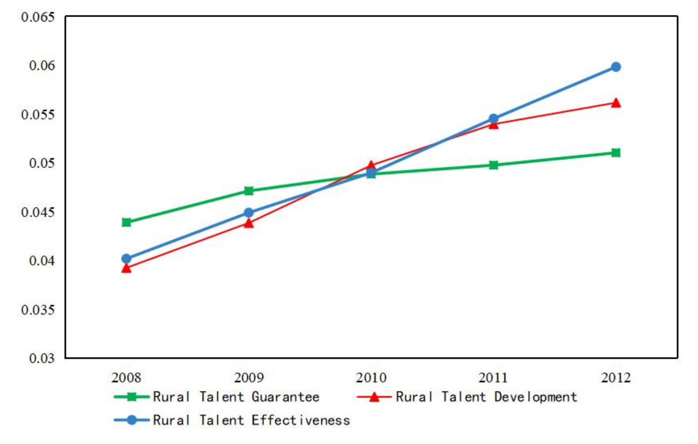

Figure 3.2: Trends of rural talent revitalization levels across dimensions, 2008 – 2012

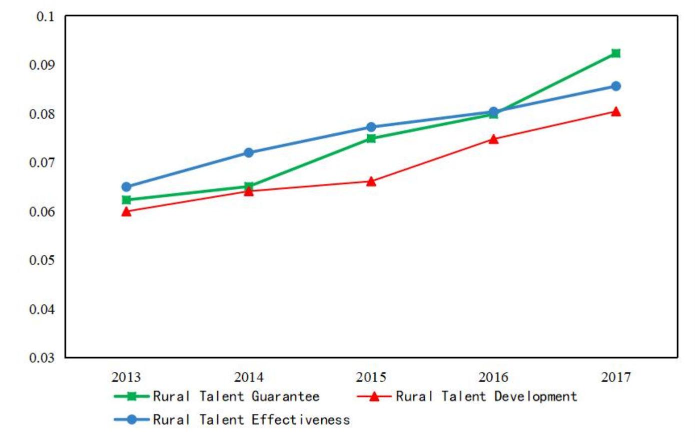

Figure 3.3: Trends of rural talent revitalization levels across dimensions, 2013-2017

From 2013 to 2017, the guarantee of rural talents accelerated, but the growth rate of construction and efficiency slowed down. As shown in Figure 3.3, in this stage, the level of rural talent security increased from 0.0623 to 0.0923, with an average annual growth rate of 10.32% and an increase of 48.15%, which was a significant increase over the previous period. This change is due to the transformation of the stage of rural development. In 2013, the No. 1 document of the Central Committee of the Communist Party of China put forward the goal of building "beautiful villages", from building a new socialist countryside to building a beautiful countryside, which injected a strong impetus into the guarantee of rural talents. This policy orientation not only improves rural infrastructure and public services, but also creates a more conducive environment for attracting and retaining talent. In this stage, the level of rural talent construction increased from 0.0600 to 0.0804, with an average annual growth rate of 7.59% and an increase of 34.00%. The efficiency level of rural talents increased from 0.0650 to 0.0856, with an average annual growth rate of 7.13% and an increase of 31.69%. At this stage, the level of rural talent protection increased most significantly, surpassing the efficiency level in 2017 and ranking first. This is mainly due to the rapid development of rural talent efficiency in the early period from 2008 to 2012, and the lack of sustained and stable talent guarantee and construction as support, resulting in insufficient subsequent growth momentum. At this point, the development pattern has changed from "efficiency-led" to "rural talen guarantee> rural talen efficiency> rural talen construction", highlighting the increasingly critical role of the basic role of rural talent guarantee.

Figure 3.4: Trends of rural talent revitalization levels across dimensions, 2018-2022

From 2018 to 2022, the guarantee of rural talents continued to be strengthened, and the construction and efficiency were steadily improved. As shown in Figure 3.4, at this stage, the level of rural talent security increased from 0.1022 to 0.1422, with an average annual growth rate of 8.62% and an increase of 39.24%. The level of rural talent construction increased from 0.08746 to 0.1345, with an average annual growth rate of 11.35% and an increase of 53.75%. The efficiency level of rural talents increased from 0.0909 to 0.1224, with an average annual growth rate of 7.72% and an increase of 34.66%. At this stage, the construction and efficiency level of rural talent have achieved rapid growth with the support of the talent guarantee in the previous stage. In 2019, the development pattern further evolved into "rural talent guarantee> rural talent construction> rural talent effectiveness", and has continued to do so since then. The stabilization of this pattern shows that the revitalization of rural talents has gradually formed a benign development model of "guarantee-based, construction-oriented, and efficiency-oriented".

3.3.3. Measurement Results and Analysis of the Level of Rural Talent Revitalization in the Region

According to the latest standards released by the National Bureau of Statistics, China's administrative regions are divided into four comprehensive economic regions, including the eastern region, the central region, the western region and the northeast region.

Figure 3.5: Heat map of the Rural Talent Revitalization Index in four regions, 2008-2022

Furthermore, this study calculated the rural talent revitalization index and its changing trend in the four major regions from 2008 to 2022, and the results are shown in Figure 3.5. From 2008 to 2022, the rural talent revitalization indices of the four regions, namely the northeast, East, West, and Central regions, all showed a continuous growth trend, with noticeable differences in development characteristics. The east region ranked first with an average annual growth rate of 7.98%. Its index jumped from 0.1662 to 0.4870, reaching 2.93 times the initial value. The revitalization level has always maintained an absolute leading position. Especially in 2013, the growth rate was 20.8%, in 2015 it was 11.6%, and in 2020 it was 8.9%. There were considerable leaps in these three years, which was closely related to the phased breakthroughs in policy innovation and industrial upgrading in the coastal areas. The central region followed closely with an average annual growth rate of 7.89%. Its index increased from 0.1271 to 0.3681, gradually widening the gap with the northeast and West regions. In 2022, it led the northeast and West regions by 13.8% and 17.0% respectively. Although the growth rate of the northeast region was 7.16%, slower than that of the east and central regions, the 15.2% growth rate increase in 2019 reflected the partial effectiveness of the northeast revitalization policy. However, its growth was relatively volatile. For example, there was a 1.2% decline in 2011, and in 2022, the index of 0.3235 was still 33.6% lower than that of the east region. The average annual growth rate of the west region was 7.27%, which was relatively lagging among the four regions. In 2022, the index of 0.3145 was only 64.6% of that of the east region. However, the 11.5% - 13.5% growth rate increase from 2019 to 2020 showed the superposition effect of the West Development and poverty alleviation. However, the excessively low base led to a still considerable absolute gap. It is worth noting that after 2020, the average annual growth rate of the northeast region was 7.5% and that of the west region was 6.9%, surpassing the east and central regions. This indicates that the resource tilt of the Rural Revitalization Strategy has begun to promote the catching-up of backward regions. However, with the continuous growth at a high base, the advantage of the east region over the west region in 2022 still expanded from 41.0% in 2008 to 54.9%, highlighting the importance of coordinated regional development.The development still needs to solve the "Matthew Effect" (A phenomenon where advanced regions accumulate advantages while lagging regions fall further behind, leading to a widening gap) (Merton, 1968) problem.

Overall, the revitalization of rural talents presents a gradient pattern where the east region leads unilaterally, the central region is poised for breakthroughs, the northeast region stabilizes and recovers, and the west region climbs arduously. In the future, it is necessary to promote balanced development through differentiated paths such as the radiation of east experience, the agglomeration of central elements, the structural transformation of the northeast, and the intensification of west policies.

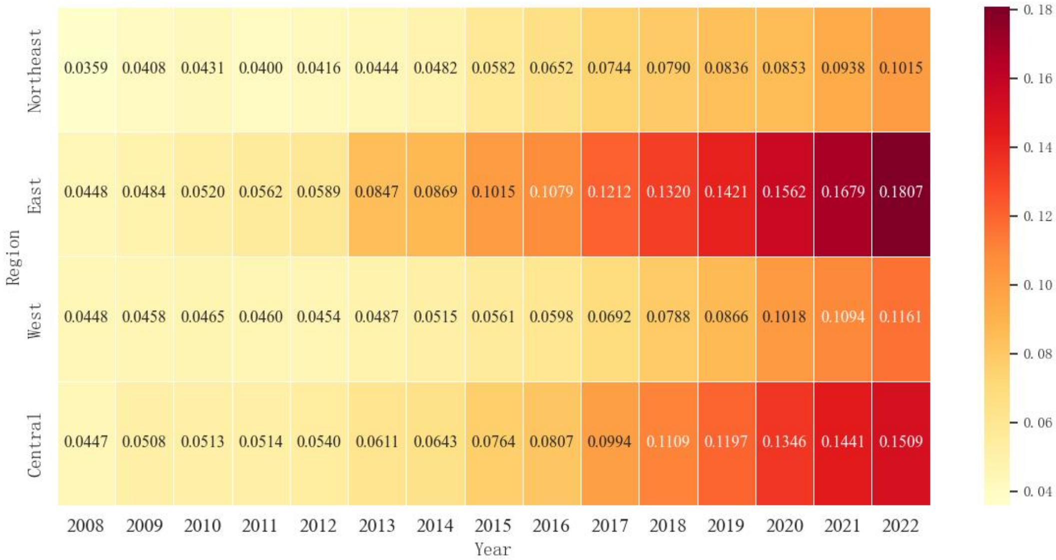

Figure 3.6: Heat map of the Rural Talent Security Index in four regions, 2008-202

As shown in Figure 3.6, in terms of rural talent security, it shows the characteristics of "the east region is absolutely leading, and the central part is catching up rapidly". The east region is significantly ahead with an average annual growth rate of 10.48%, and its index has increased from 0.0448 to 0.1807, an increase of 303%, and especially in 2013, it has achieved an explosive jump of 43.8% in a single year, from 0.0589 to 0.0847, forming a continuous leading advantage; The central region followed with a growth rate of 9.08%, and in 2017, through a phased high growth rate of 23.3%, it rose from 0.0807 to 0.0994 to achieve a reversal of the northeast, and the index of 0.1509 in 2022 was 48.6% higher than that of the northeast region of 0.1015, but there was still an absolute gap of 19.7% compared with the east. Although the growth rate of 7.70% in the northeast region was higher than that of 7.04% in the west, the abnormal decline of 7.2% in 2011 due to policy adjustment, from 0.0431 to 0.0400, weakened the long-term growth stability. Although the growth rate of the west region peaked at 17.6% in 2020, rising from 0.0866 to 0.1018, it was limited by the continuous negative growth in 2011 and 2012, declining by 1.1% and 1.3% respectively, and the index of 0.1161 in 2022 was only 64.2% of that of the east region in the same period, and the gap in inter-regional support capacity widened by 13.5 percentage points compared with 2008.

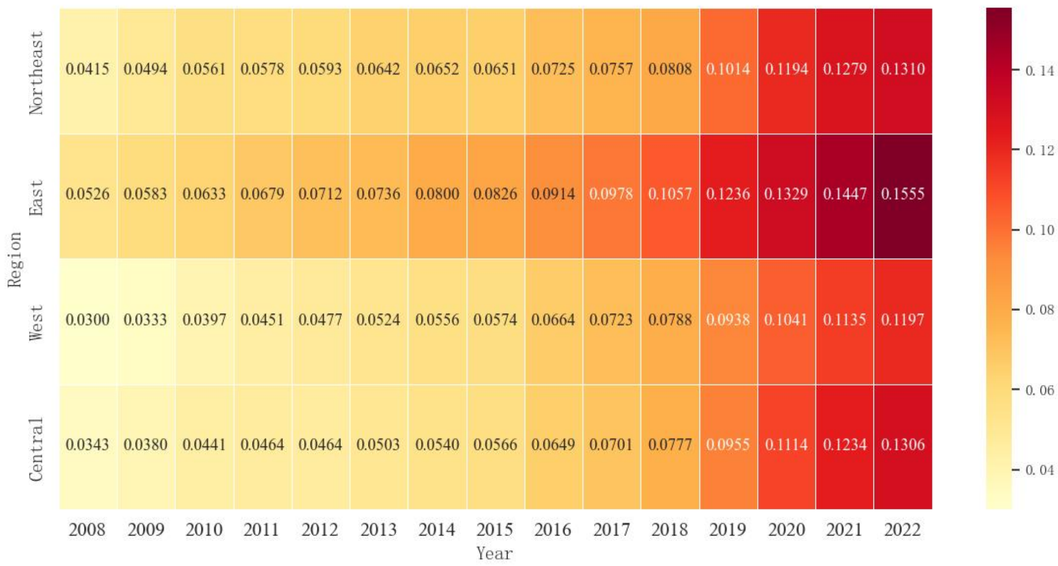

Figure 3.7: Heat map of Rural Talent Construction Index in four regions, 2008-2022

As shown in Figure 3.7, there is a completely different competitive pattern in the construction of rural talents, with the western region reaching the top with an average annual growth rate of 10.38%, and its index increasing from 0.0300 to 0.1197, an increase of 300%, and in 2011 and 2013, it rapidly narrowed the gap with the eastern region through a high growth rate of more than 15% for three consecutive years, and by 2022, its talent construction level has reached 77.0% of that of the eastern region; The central region maintained a strong catch-up with a growth rate of 10.02%, and the northeast had 0.1310. Although the east region is at the bottom with a growth rate of 8.05%, it still leads the west region by 30.0% in 2022 with the base advantage of 0.1555 accumulated in the early stage. Although the growth rate of 8.55% in the northeast region is higher than that in the east, the policy gap in 2015 led to the stagnation of the construction process, exposing the shortcomings of growth sustainability. It is worth noting that the growth advantage of the west region in the construction sector has produced a substantial catch-up effect, and its 2022 index has quadrupled compared with 2008, which is noticeably higher than the three-fold growth rate of the east region.

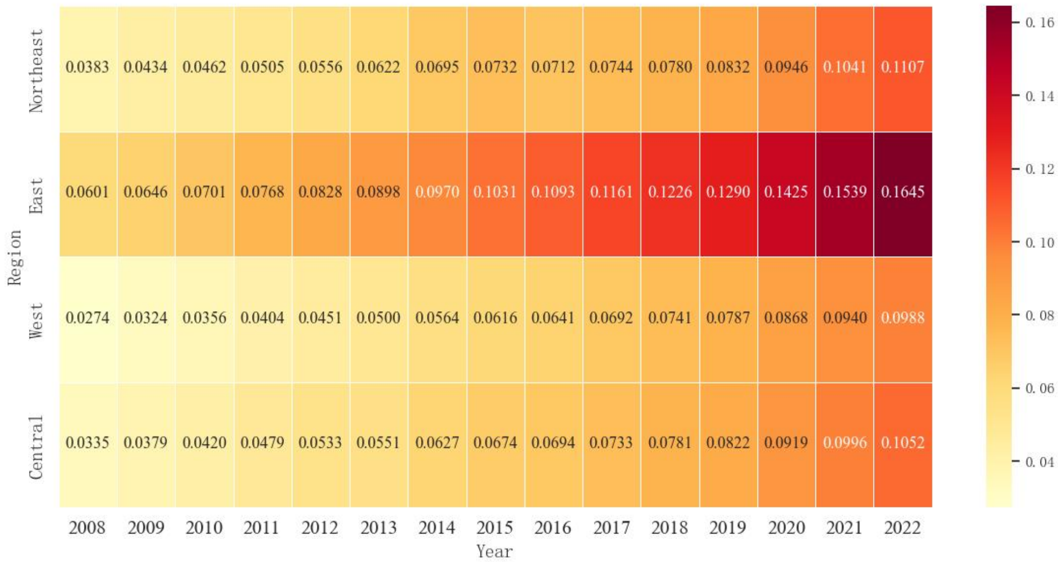

Figure 3.8: Heat map of the Rural Talent Effectiveness Index in four regions, 2008-2022

As shown in Figure 3.8, the west region ranked first with an average annual growth rate of 9.61%, with the index increasing from 0.0274 to 0.0988, an increase of 261%, and the growth rate exceeded the 10% growth threshold in 2020 to reach a historical peak, but the level value in 2022 was still only 59.8% of that in the east. The central region continued to optimize with a growth rate of 8.51%, and after 2019, through a three-year cumulative growth of 28.1%, it increased from 0.0822 to 0.1052, gradually narrowing the gap with northeast China, and its level has reached 95.0% of northeast China by 2022. Although the growth rate of 7.45% in the east region is the lowest among the four regions, the index of 0.1645 in 2022 still maintains an absolute lead. Its level increases by 2.74 times compared to 2008, which is lower than the 3.61 times in the west, indicating that the first-mover advantage is facing dilution risks. The growth rate of 7.89% in the northeast region fluctuated significantly, and in 2016 it fell by an unusual 2.8%.

The comprehensive analysis shows that the four regions show differentiated paths in the three dimensions of rural talent development: the eastern region relies on high talent guarantee investment to maintain scale advantage, but faces the pressure of weak growth in talent efficiency; The central part of the country has achieved overtaking through high-intensity investment in the field of talent construction, and it is necessary to be vigilant against the risk of lagging talent efficiency transformation; The western region has accelerated its catch-up with an unconventional strategy of prioritizing talent and effectiveness, but the weak guarantee of basic talents may restrict sustainability. The low-speed balanced growth in the whole dimension of northeast China is superimposed on cyclical fluctuations, highlighting the resistance to systemic transformation. In the future, policy design needs to be targeted to solve regional bottlenecks: the eastern part should promote the coordinated reform of "talent security and talent efficiency", the central part should strengthen the transmission mechanism of "talent construction and talent efficiency", the western part urgently needs to implement the "talent guarantee make-up plan", and the northeast must build an "anti-fluctuation policy system" to achieve a dynamic balance of rural talent development through differentiated paths.

3.3.4. Measurement Results and Analysis of the Level of Rural Talent Revitalization at the Provincial level

The Rural Talent Revitalization Index and its sub-dimensional indices in each province of China in 2022 are shown in Table 3.4. There are obvious differences in the performance of rural talent revitalization among different provinces in China. Overall, the eastern coastal provinces of Shanghai, Beijing, Zhejiang, Jiangsu, and Fujian performed prominently in the Rural Talent Revitalization Index, with Shanghai and Beijing in particular ranking in the top two with high scores of 0.6217 and 0.6132, respectively. These regions not only lead in the overall level of rural talent revitalization, but also perform well in the dimensions of rural talent security, rural talent construction and rural talent efficiency. For example, Shanghai ranked first in rural talent effectiveness, Beijing topped the list in rural talent development, and Zhejiang performed best in rural talent security. The advantages of these areas are mainly due to their developed economic foundation, strong policy support and high talent attraction, which makes the revitalization of rural talents smoothly promoted. In contrast, the rural talent revitalization index in the central and western regions is generally low, especially in Tibet, Yunnan, Guizhou and other provinces, which rank relatively low. Tibet's rural talent revitalization index is only 0.2469, ranking last, and its three sub-indices of rural talent security, rural talent construction and rural talent efficiency are also at a low level. Due to the relative lag of economic development, imperfect infrastructure, and weak talent attraction in these areas, the revitalization of rural talents is facing great challenges. Although some central and western provinces have performed well in individual sub-dimensions, such as Xinjiang ranked third in rural talent development and Qinghai ranked sixth in rural talent effectiveness, there is still a big gap compared to the eastern coastal areas as a whole.

From the perspective of sub-dimensions, in terms of the rural talent security index, eastern provinces such as Zhejiang, Fujian and Jiangsu performed prominently, while central and western provinces such as Tibet, Inner Mongolia and Jilin were relatively lagging behind. The guarantee of rural talents mainly involves the support of talent policies and the improvement of living conditions, and the eastern region, with its strong economic strength and policy implementation ability, can provide better guarantee conditions for rural talents. However, due to limited resources in the central and western regions, it is difficult to implement policies, resulting in a low level of rural talent security. In terms of the rural talent construction index, Beijing, Shanghai, Xinjiang and other provinces performed well, especially Beijing ranked first in the construction of rural talents, showing its advantages in the training, introduction and use of talents. As a western region, Xinjiang has been able to achieve relatively good results in the development of qualified personnel in rural areas, which may be related to the increase in its investment in education and personnel training in recent years. In terms of the rural talent effectiveness index, eastern provinces such as Shanghai, Beijing, and Zhejiang still lead the way, showing the advantages of these regions in terms of talent utilization efficiency and contribution. However, in the central and western provinces, such as Tibet, Yunnan, and Guizhou, due to the serious brain drain, the efficiency of talent utilization is low, resulting in a generally low talent efficiency index in rural areas.

Overall, the performance of China's provinces in the revitalization of rural talents shows obvious regional differences, with the eastern coastal region leading the way and the central and western regions lagging behind. This disparity not only reflects the disparity in the level of economic development between regions, but also reveals the impact of multiple factors such as policy support, infrastructure, and talent attraction.

Table 3.4: Rural Talent Revitalization Index and Sub-dimensional Indices of Chinese Provinces in 2022

Rank	Rural Talent Revitalization		Rural Talent Security		Rural Talent Development		Rural Talent Efficiency	
1	Shanghai	0.6217	Zhejiang	0.2504	Beijing	0.2195	Shanghai	0.2332
2	Beijing	0.6132	Fujian	0.2310	Shanghai	0.2175	Beijing	0.2268
3	Zhejiang	0.5195	Jiangsu	0.2304	Xinjiang	0.1662	Zhejiang	0.1879
4	Jiangsu	0.5066	Hebei	0.1918	Shandong	0.1655	Tianjin	0.1808
5	Fujian	0.4983	Guangdong	0.1896	Tianjin	0.1592	Jiangsu	0.1632
6	Shandong	0.4719	Shandong	0.1787	Fujian	0.1559	Qinghai	0.1515
7	Guangdong	0.4594	Henan	0.1691	Inner Mongolia	0.1494	Shandong	0.1418
8	Tianjin	0.4197	Shanghai	0.1640	Hubei	0.1456	Fujian	0.1411
9	Hebei	0.4128	Beijing	0.1639	Jilin	0.1442	Ningxia	0.1329
10	Henan	0.3862	Jiangxi	0.1616	Guangdong	0.1420	Guangdong	0.1296
11	Jiangxi	0.3840	Anhui	0.1498	Ningxia	0.1415	Hainan	0.1248
12	Hubei	0.3812	Hunan	0.1460	Jiangsu	0.1411	Liaoning	0.1230
13	Anhui	0.3789	Hubei	0.1444	Hainan	0.1388	Hebei	0.1161
14	Xinjiang	0.3636	Xinjiang	0.1407	Jiangxi	0.1366	Hunan	0.1152
15	Hunan	0.3560	Chongqing	0.1352	HeilongJiang	0.1339	Anhui	0.1138
16	Qinghai	0.3507	Shanxi	0.1347	Hunan	0.1303	Inner Mongolia	0.1132

Rank	Rural Talent Revitalization		Rural Talent Security		Rural Talent Development		Rural Talent Efficiency	
17	Ningxia	0.3482	Guangxi	0.1335	Anhui	0.1296	Hubei	0.1109
18	Hainan	0.3468	Sichuan	0.1333	Henan	0.1267	HeilongJiang	0.1049
19	Chongqing	0.3291	Shaanxi	0.1207	Qinghai	0.1267	Jilin	0.1043
20	Liaoning	0.3282	Guizhou	0.1180	Gansu	0.1209	Gansu	0.1021
21	Inner Mongolia	0.3266	Yunnan	0.1150	Shaanxi	0.1185	Henan	0.1019
22	Shaanxi	0.3229	Gansu	0.1122	Chongqing	0.1162	Jiangxi	0.0999
23	Shanxi	0.3222	Hainan	0.1105	Liaoning	0.1149	Guangxi	0.0942
24	HeilongJiang	0.3218	Ningxia	0.1067	Shanxi	0.1148	Chongqing	0.0927
25	Guangxi	0.3210	Liaoning	0.1043	Guangxi	0.1134	Shaanxi	0.0910
26	Jilin	0.3206	HeilongJiang	0.1035	Zhejiang	0.1099	Shanxi	0.0896
27	Gansu	0.3158	Qinghai	0.1000	Guizhou	0.1058	Yunnan	0.0882
28	Sichuan	0.3130	Jilin	0.0968	Hebei	0.1055	Xinjiang	0.0839
29	Guizhou	0.2712	Tianjin	0.0963	Tibet	0.0954	Sichuan	0.0832
30	Yunnan	0.2655	Inner Mongolia	0.0934	Sichuan	0.0950	Guizhou	0.0820
31	Tibet	0.2469	Tibet	0.0840	Yunnan	0.0878	Tibet	0.0710

In order to further explore the dynamic evolution characteristics of rural talent revitalization in different provinces, this study conducts an in - depth analysis of the changes in the ranking of rural talent revitalization levels in 31 provinces of China. The specific results are shown in Figure 3.9.

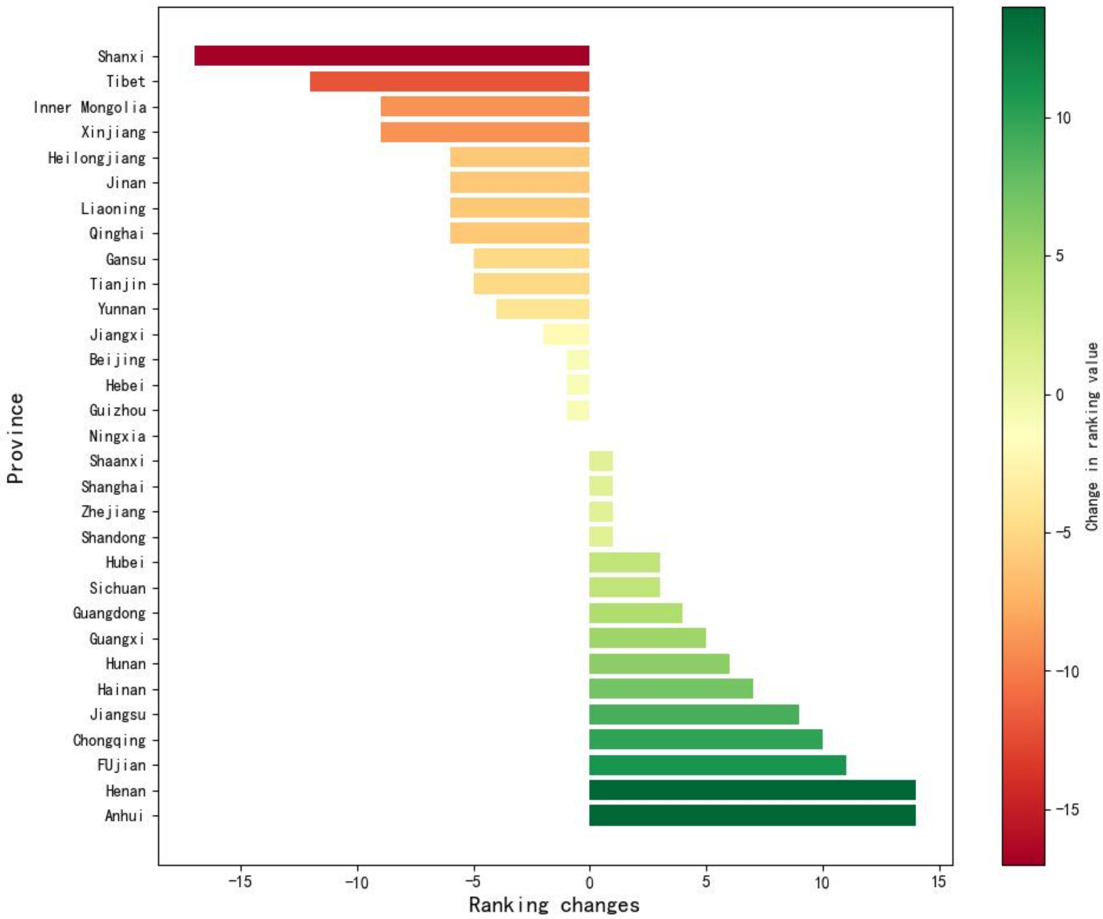

Figure 3.9: Changes in the ranking of provinces from 2008 to 2022

On this basis, this study further analyses the absolute increase and average annual growth rate of the rural talent revitalization level in each province, and quantitatively measures these data. In order to classify these data more accurately, this study adopts the natural breakpoint method, which is theoretically supported by the Jenks optimization algorithm(Liu et al., 2023). The core advantage of this method is that it can accurately lock the optimal grouping breakpoints, and achieve optimal classification of data by expanding the differences between groups while compressing the variance within the group to a minimum. The specific operation process is as follows: First, arrange all the observed data in ascending order. Then, through repeated iterative calculations, calculate the ratio of the sum of squared deviations within groups to the total sum of squared deviations under different grouping strategies one by one. Finally, select the grouping threshold that can maximize the within-group homogeneity. Through the above method, this study carefully divides the average annual growth rate of the rural talent revitalization level of each province into four groups to deeply analyse the development trend of rural talent revitalization in each province. The specific classification results are shown in Figure 3.10.

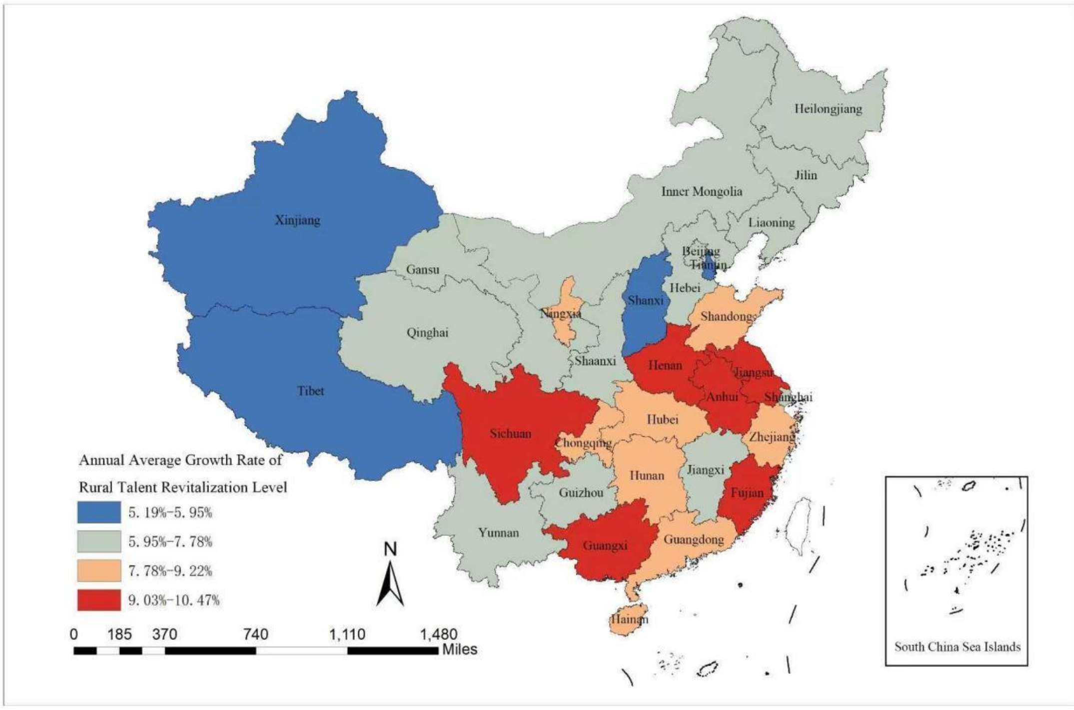

Figure 3.10: Average annual growth rate of rural revitalization by province from 2008 to 2022

From the ranking of the rural talent revitalization level in each province, the rankings of the vast majority of provinces show a trend of either rising or falling. Only the ranking of the Ningxia Hui Autonomous Region remains stable without any change. A detailed examination reveals that the rankings of 15 provinces have climbed to varying degrees. Among them, the rankings of Anhui, Fujian, Henan, Chongqing, Guangxi, Hainan, Hunan, Jiangsu and other provinces have increased by 5 positions or more, which fully demonstrates that these regions have made remarkable progress in rural areas. Remarkable results have been achieved in the field of talent revitalization. In-depth exploration found that most of the provinces that rose in the ranking achieved breakthroughs by virtue of the precise targeting of policies and the high degree of adaptation and synergy of industries. Taking Anhui, Jiangsu, Fujian and other places as examples, they actively promote the "industrial chain + talent chain" collabourative linkage model, and the results are remarkable. Anhui focuses on the field of characteristic agriculture, vigorously supports entrepreneurial projects returning to their hometowns, and provides a broad space for the development of rural talents (Cheng, 2024); Jiangsu has made every effort to promote the in-depth placing of universities and agricultural parks, realize the integrated development of industry and education, and provide a large number of professional talents for rural areas (Tian, 2023); Fujian has leveraged the advantages of digital infrastructure to empower the rural e-commerce industry, creating a new highland for rural talent gathering, and successfully building a benign interactive closed loop of "industrial upgrading and talent gathering" (Wu, 2024).

In contrast, another 15 provinces have seen varying degrees of decline in their rankings, with Gansu, Heilongjiang, Jinan, Liaoning, Inner Mongolia, Qinghai, Shanxi, Tianjin, Tibet and Xinjiang all falling by more than five places, with Shanxi and Tibet dropping by 17 and 12 places respectively. northeast China is deeply troubled by the dual problems of population outflow and lagging industrial transformation, and the path dependence of the traditional economic development model is seriously disconnected from the emerging industries, resulting in a prominent talent fault (Guo, 2021). Shanxi, Tibet and other places have exposed the shortcomings of lack of policy flexibility and unbalanced resource allocation (Hu et al., 2025); Due to the limitation of geographical location and the simplification of the industrial structure, the attraction of talents in Northwest China is becoming more and more insufficient, which in turn profoundly reflects the deep-seated contradiction of unbalanced regional development (Li et al., 2021). These problems are not only related to the rural development of individual provinces, but also have a far-reaching impact on the overall pattern of rural talent revitalization across the country, and it is urgent to solve them with targeted strategies.

From the perspective of the change trend of the revitalization level of rural talents in each province, the level of rural talent revitalization in each province generally shows an upward trend, but there are obvious differences between provinces. In terms of the change range, the regions with the highest absolute increase in rural talent revitalization are Beijing (0.3630), Fujian (0.3747), Guangdong (0.3223), Jiangsu (0.3738), Shandong (0.3134), Shanghai (0.3784) and Zhejiang (0.3484). Guizhou (0.1673), Shanxi (0.1635), Tibet (0.1263) and Yunnan (0.1572) had a low absolute growth rate in rural talent revitalization. In terms of average annual growth rates, the average annual growth rates of Fujian (10.47 percent), Sichuan (10.11 percent), Jiangsu (10.04 percent), Henan (9.42 percent), Anhui (9.60 percent), and Guangxi (9.36 percent) were all above 9 percent, while the average annual growth rates of Shanxi (5.19 percent), Tianjin (5.95 percent), Tibet (5.25 percent), and Xinjiang (5.56 percent) were relatively low, all of which did not exceed 6 percent. From the perspective of geographical distribution characteristics, the development trend of the revitalization level of rural talents in China shows a trend of "high in the east and low in the west, fast in the south and slow in the north". The areas with high growth rates are concentrated in the central and eastern coastal areas, and the areas with low growth rates are concentrated in the western border areas. The areas with high average annual growth rate are mostly concentrated in the south of the Huai River in the Qinling Mountains, and the areas with low average annual growth rate are mostly concentrated in the north of the Huai River in the Qinling Mountains. The high growth rate and rapid growth rate of the eastern coastal and southern provinces are essentially due to the coordinated upgrading of "economy-industry-talent". For example, Shanghai, Jiangsu, Zhejiang and other places led the way in absolute growth (all exceeding 0.3), which is inseparable from their strong financial strength. On the other hand, in the northern provinces, except for Henan and Shandong, which rely on their population size and agricultural base to maintain a medium-speed growth. Shanxi, Tianjin and other places are constrained by path dependence on traditional industries, with policy-industry mismatches leading to insufficient momentum for talent revitalization. The predicament of low-growth regions exposes systematic weaknesses. Tibet's absolute increase is only 0.1263, which is ostensibly due to the short-term aid policy and the scarcity of local vocational colleges (Li et al., 2022), but the deep contradiction lies in the disconnect between "blood transfusion" and "hematopoiesis", making it difficult for external aid talents to take root in Tibet. Local young people rarely return to their hometowns after passing the college entrance examination, resulting in long-term dependence on "seasonal migratory bird talents" in Tibetan medicine, tourism and other fields.

3.4. Summary of this Chapter

This chapter conducts a systematic study on the measurement of the level of rural talent revitalization, constructs a three-level evaluation system of "target layer, dimension layer, and index layer", selects 21 specific indicators from the three dimensions of talent security, talent construction, and talent efficiency, and comprehensively uses the entropy weight-TOPSIS model to quantitatively evaluate the level of rural talent revitalization in 31 provinces in China from 2008 to 2022. The construction of the index system follows the principles of scientificity and representativeness, systematization and hierarchy, quantification and objectivity, covering core elements such as infrastructure, capital investment, cultivation platform, scale structure, quality level, innovation and transformation, production efficiency, and rural improvement. The data source integrates 12 national authoritative yearbooks and provincial statistical data, establishes a mixed measurement method for special indicators such as the number of people in the "three branches and one support" and the number of "Taobao villages", and uses multiple techniques such as similar regional imputation, time series analysis, and regression modelling to deal with the problem of missing data in Tibet and other regions.

The study found that the level of rural talent revitalization in China showed a stepwise increase, with the overall index increasing from 0.1357 in 2008 to 0.3814 in 2022, an increase of 181%, and experienced a three-stage evolution of "slow climbing (2008-2012)-accelerated development (2013-2017)-steady improvement (2018-2022)". The weight distribution of the dimension layer shows that talent construction (36.63%) contributes the highest to the total index, and the scale of talents in rural secondary and tertiary industries (10.68%), the scale of e-commerce platforms (9.92%), and the number of invention patent applications per capita (8.85%) become the key driving indicators. The dynamics of different dimensions show that talent security, talent construction, and talent efficiency increased by 2.24 times, 2.43 times, and 2.05 times, respectively, forming a virtuous cycle pattern that is "security-based, construction-centreed, and efficiency-oriented" after 2018.

The regional level analysis presents the characteristics of gradient development. The eastern region maintained an absolute lead with an average annual growth rate of 7.98%, and the index (0.4870) in 2022 reached 1.55 times that of the western region (0.3145). The comparison of different dimensions shows that the eastern region leads in the dual dimensions of talent security (0.1807) and talent efficiency (0.1645), the western region ranks first in the growth rate of talent construction (0.1197), the central part of the country lags behind in the transformation of talent efficiency, and the northeast shows medium and low-speed fluctuating growth in all dimensions.

At the provincial level, Shanghai (0.6217), Beijing (0.6132) and Zhejiang (0.5195) ranked the top three, while Tibet (0.2469), Yunnan (0.2655) and Guizhou (0.2712) continued to rank at the bottom. The sub-dimensional characteristics show that Shanghai leads in the dimensions of talent effectiveness (0.2332) and talent construction (0.2175), but talent guarantee (0.1640) is lower than that of Zhejiang (0.2504). Beijing leads the way in terms of talent development (0.2195), while Xinjiang ranks among the top three with talent construction (0.1662), highlighting the policy tilt effect of talent cultivation in the western region. The central and western provinces showed unbalanced characteristics: Qinghai ranked in the top six in talent efficiency (0.1515), but talent guarantee (0.1000) ranked last; Henan, Anhui and other major agricultural provinces showed differentiation in talent construction (0.1267, 0.1296) and efficiency (0.1019, 0.1138). This reflects the lack of matching between production and talent. Tibet is at the bottom of the three dimensions of talent security (0.0840), construction (0.0954) and efficiency (0.0710), exposing the systemic shortcomings of talent revitalization in border areas. In the dynamic evolution, 15 provinces, including Anhui and Fujian, have risen by more than 5 places, mainly due to the synergistic effect of the industrial chain and the talent chain. Fifteen provinces, including Shanxi and Tibet, fell in the rankings, reflecting the dilemma of population outflow and policy rigidity in the northeast and northwest regions. The absolute growth rate and average annual growth rate showed the spatial characteristics of "high in the east and low in the west, fast in the south and slow in the north", with coastal provinces such as Fujian (10.47%) and Jiangsu (10.04%) leading the growth rate, while northern provinces such as Shanxi (5.19%) and Tibet (5.25%) had a growth rate of less than 6%.

Chapter 4

Analysis of Spatiotemporal Characteristics of Rural Talent Revitalization

4.1. Measurement and Evolution Analysis of Spatiotemporal Differences

The spatial differences and dynamic evolution of rural talent revitalization are important bases for policy formulation. In this study, the Dagum Gini coefficient decomposition method and kernel density estimation method were used to systematically measure the spatial differences and sources of the rural talent revitalization index in China and the four major comprehensive economic regions from 2008 to 2022, and to analyse the temporal evolution law, aiming to reveal the internal mechanism of regional development imbalance. this work analyses the performance of different regions in the revitalization of rural talents and their relationship with each other, and gives a deeper understanding of the spatial differences and dynamic evolution of rural talent revitalization, so as to provide a scientific basis for policy formulation.

4.1.1. Decomposition of Regional Differences in Rural Talent Revitalization

When analyzing regional differences, scholars usually use methods such as the Coefficient of Variation (CV), the Gini coefficient (Gini) (Cowell, 2011), and the Theil index to calculate and analyse (Theil, 1967). These methods can measure the degree of regional disparities to a certain extent, and can show the general situation of regional level imbalances at the macro level. However, when it comes to the detailed decomposition of regional differences and in-depth exploration of the root causes of differences and the composition of each part, these methods have obvious limitations, and it is difficult to accurately analyse the complex internal structure behind regional differences. Dagum made an innovative improvement on the classical Gini coefficient method and creatively proposed the Dagum Gini coefficient method (Dagum et al., 2000). The significant advantage of this method is that it breaks through the limitation of traditional methods that can only reflect the appearance of regional differences, and can not only accurately measure the degree of regional differences, but more importantly, it can skilfully disassemble the overall regional differences into disparities from different sources, so as to dig deeper into the internal causes of regional differences. Furthermore, it can also be used as a basis to analyse the contribution proportion of different regions in the formation of overall regional differences, which provides a new perspective for the study of regional differences. The advantage of this method is that it can solve the problem of cross-overlap between regions, and can further analyse the differences between groups and within groups, calculate the corresponding contribution rate, and understand the sources of regional differences in more detail. At present, this method has been widely used in the exploration of various regional differences in many fields, and has become a powerful tool for academic research on regional differences (Zhang et al., 2022). Specifically, the Dagum Gini coefficient (G) can be deconstructed into three key components, namely the contribution of intra-regional differences (G_w) , which represents the contribution of intra-group disparities to the Gini coefficient, reflecting within regions the degree of imbalance; The contribution of regional differences (G_{nb}) represents the contribution of net differences between groups to the Gini coefficient, reflecting the overall differences between different regions. The contribution of transvariation (G_t) indicates the contribution of supervariable density to the Gini coefficient between groups, reflecting the distributional overlap between different regions. In this study, the relevant data processing and analysis were carried out by Matlab 2022, and the relevant calculations are as follows:

Step 1: Calculate the overall difference in the rural talent revitalization index of each province across the country (G).

$$G = \frac{1}{2n^2\bar{y}}\sum_{j=1}^{m}\sum_{h=1}^{m}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{hr}|. \quad (4.1)$$

In Eq. (4.1), n is the total number of provinces, m is the number of regions, n_j (n_h) represents the number of provinces in the j(h) region, $\bar{y}$ is the overall mean value of the rural talent revitalization index, and $y_{ji}(y_{hr})$ represents the index value of the i-th (r-th) province in the j-th (h-th) region.

Step 2: Calculate the within-region difference (G_{jj}) and the contribution of the within-region difference (G_w).

$$G_{jj} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji}-y_{jr}|}{2n^2\bar{y}}\ , \quad (4.2)$$

$$G_w = \sum_{j=1}^{m} G_{jj}P_jS_j\ . \quad (4.3)$$

In Equation (4.2), y_{ji} and y_{jr} represent the index values of the i-th (r-th) provinces within the j-th region. In Equation (4.3), $P_j = n_j/n$, $S_j = n_j\bar{y}_j/n\bar{y}$.

Step 3: Calculate the inter - regional difference (G_{jh}) and the contribution of inter - regional difference (G_{nb}).

$$G_{jh} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji}-y_{jr}|}{n_jn_h(\bar{y}_j+\bar{y}_h)}\ , \quad (4.4)$$

$$G_{nb} = \sum_{j=2}^{m}\sum_{h=1}^{j-1} G_{jh}(P_jS_h + P_hS_j)D_{jh}\ . \quad (4.5)$$

In Eq. (4.5), $P_h = n_h/n$, $S_h = n_h\bar{y}_h/n\bar{y}$, D_{jh} represents the relative influence of the comprehensive scores of the rural talent revitalization index between the j-th and h-th regions.

Step 4: Calculate the contribution rate of transvariation (G_t).

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \ , \tag{4.6}$$

$$G_t = \sum_{j=2}^{m} \sum_{h=1}^{j-1} G_{jh}(P_j S_h - P_h S_j)(1 - D_{jh}) \ . \tag{4.7}$$

In Equations (4.6) and (4.7), d_{jh} is the difference of the rural talent revitalization index between regions, i.e., the expected value of the sum of sample values where $y_{ji} > y_{hr}$ for all samples in the j-th and h-th regions; p_{jh} is the first - order moment of transvariation, i.e., the expected value of the sum of sample values where $y_{ji} > y_{hr}$ for all samples in the j-th and h-th regions.

(1) Overall Differences and Regional Differences

Figure 4.1 shows the Gini coefficient and its evolution trend of the Rural Talent Revitalization Index in China and the four major regions. From a national perspective, the Gini coefficient of the Rural Talent Revitalization Index showed a fluctuating downward trend, and the overall regional differences gradually narrowed. Specifically, the Gini coefficient decreased from 0.1399 in 2008 to 0.1271 in 2022. During this period, there was a period of upward volatility from 2010 to 2016, but since 2017 it has maintained a steady downward trend. It can be seen that in recent years, the development of rural talent revitalization has become more balanced across the country, and the gap between regions has narrowed, indicating that relevant policies and measures have achieved certain results in promoting the revitalization of rural talents, and the level of rural talent development between different regions is gradually becoming balanced. From the microstructure of regional differences, the Gini coefficient of the rural talent revitalization index in the four regions showed a downward trend, and the magnitude and evolution processes of the values were different. In terms of the mean Gini coefficient of each region, the eastern region (0.1071) > the western region (0.0891) > the central region (0.0428) > the northeast region (0.0164), indicating that the uneven level of rural talent revitalization in the eastern region is greater than that in other regions.

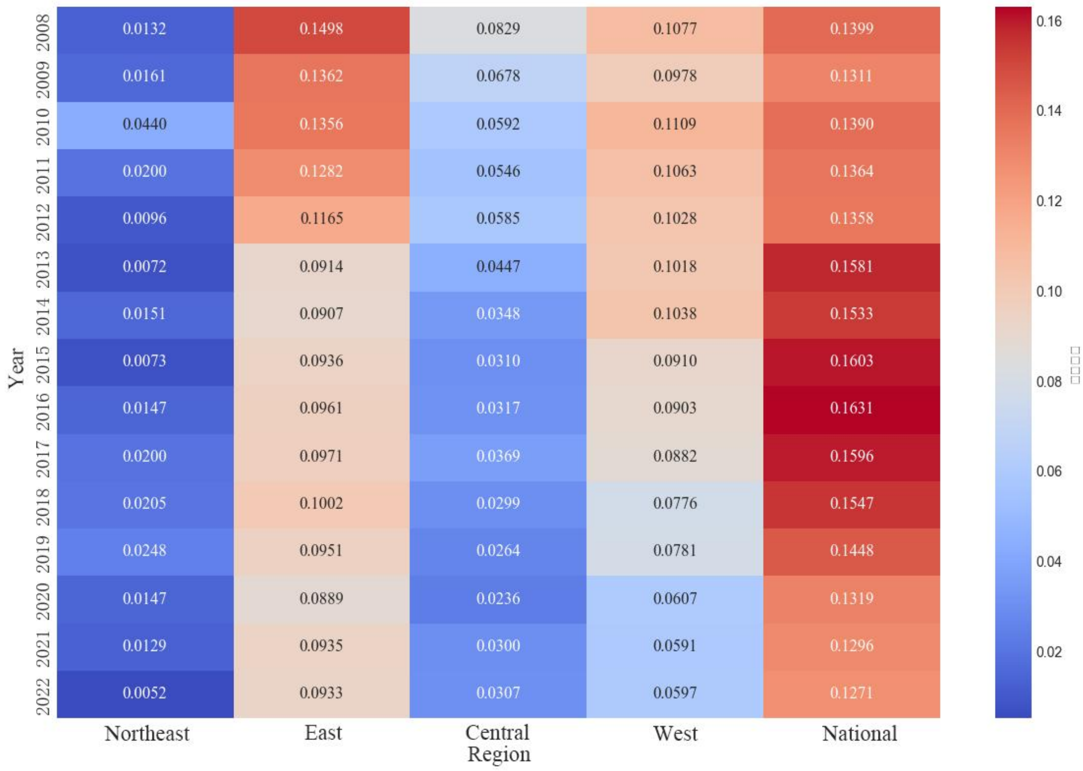

Figure 4.1: Gini coefficient heatmap of rural talent revitalization index by region & country, 2008-2022

From the perspective of the evolution trend of the Gini coefficient in each region, the intra-group Gini coefficient in the eastern region showed a fluctuating downward trend from 2008 to 2022, from 0.1498 in 2008 to 0.0933 in 2022, indicating that the difference in the level of rural talent revitalization in the eastern region gradually narrowed. Although the decline is obvious, the Gini coefficient remained at a high level throughout the entire period, indicating that the imbalance in the level of rural talent revitalization in the eastern region is still relatively prominent. The intra-group Gini coefficient in northeast China fluctuated from 2008 to 2022, showing a trend of first decreasing, then increasing and then decreasing. It was 0.0132 in 2008, and then fluctuated significantly, reaching 0.0052 in 2022, indicating that the difference in the level of rural talent revitalization in northeast China was not stable during this period, and there were certain fluctuations, but on the whole, it reached a low level in 2022, indicating that the difference in the level of rural talent revitalization in northeast China in that year was small. The Gini coefficient in the central region decreased from 0.0829 in 2008 to 0.0307 in 2022, showing an overall downward trend, but showing an upward trend after 2020. This results show that from 2008 to 2020, the intra-regional differences in the level of rural talent revitalization in the central region gradually narrowed, and the development of rural talent revitalization became more balanced. However, an increase in the Gini coefficient after 2020 could mean that intra-regional imbalances have increased. The Gini coefficient in the western region decreased from 0.1077 in 2008 to 0.0597 in 2022. However, because its average Gini coefficient is second only to the eastern region during the entire time period, it indicates that the imbalance in the level of rural talent revitalization in the western region needs to be taken seriously.

(2) Inter-regional Differences and Evolution Trends

Further analysis of the four regional differences in China's rural talent revitalization index shows that the changes in the Gini coefficient between groups from 2008 to 2022 reflect the evolution of the imbalance between the levels of rural talent revitalization in the four major economic regions, as shown in Table 4.1. The Gini coefficient of the eastern and northeastern regions fluctuated from 0.1602 in 2008 to 0.2017 in 2022, indicating that the difference in the level of rural talent revitalization between the two regions has increased as a whole, indicating that the imbalance between the two regions has intensified. Especially in the period 2013-2018, the gap has been widening. The Gini coefficient of the eastern and central regions decreased from 0.1611 in 2008 to 0.1450 in 2022, indicating that the imbalance between the two regions has improved, but the decline is small and there is an upward phase during the period, and the balanced development still faces challenges. The Gini coefficient of the eastern and western regions fluctuated from 0.1919 in 2008 to 0.2707 in 2016, and then decreased to 0.2156 in 2022. The Gini coefficient of northeast and central China showed a U-shaped trend from 0.0643 in

2008 to 0.0654 in 2022. The Gini coefficient of the northeast and west regions fluctuated from 0.0789 in 2008 to 0.0408 in 2022, and the downward trend was obvious, indicating that the imbalance between the two regions has been considerably improved. The Gini coefficient of the central and western regions fluctuated from 0.1021 in 2008 to 0.0831 in 2022, a significant decrease, reflecting that the imbalance in the level of rural talent revitalization between the central and western regions has been effectively alleviated.

Table 4.1: Gini coefficients comparing the four regional groups

Year	northeast-Eastern	northeast-Central	northeast-Western	Eastern-Central	Eastern-Western	Central-Western
2008	0.1602	0.0643	0.0789	0.1611	0.1919	0.1021
2009	0.1333	0.0578	0.0879	0.1491	0.1883	0.0944
2010	0.1405	0.0589	0.1047	0.1552	0.1990	0.1015
2011	0.1607	0.0452	0.0885	0.1582	0.1966	0.0980
2012	0.1647	0.0456	0.0855	0.1621	0.1990	0.0965
2013	0.2183	0.0326	0.0838	0.2211	0.2538	0.0896
2014	0.2106	0.0287	0.0852	0.2107	0.2456	0.0887
2015	0.2329	0.0265	0.0762	0.2212	0.2670	0.0855
2016	0.2374	0.0305	0.0771	0.2288	0.2707	0.0827
2017	0.2392	0.0521	0.0704	0.2022	0.2671	0.0922
2018	0.2451	0.0692	0.0617	0.1888	0.2596	0.0906
2019	0.2211	0.0644	0.0647	0.1700	0.2427	0.0931
2020	0.2150	0.0749	0.0451	0.1539	0.2241	0.0865
2021	0.2050	0.0696	0.0431	0.1488	0.2195	0.0867
2022	0.2017	0.0654	0.0408	0.1450	0.2156	0.0831

In terms of phases, the period from 2008 to 2012 is the initial stage of discrepancy. The Gini coefficients of the eastern and northeastern regions and the eastern and western regions all showed a slight upward trend, reflecting that after the 2008 global financial crisis, the eastern region took the lead in recovering with strong economic resilience, while the northeast and western regions were affected by the decline of traditional industries and lagging infrastructure, and the level of talent revitalization was relatively lagging behind. In particular, the northeast region, as an old industrial base, is facing the pressure of industrial restructuring and the development gap between the eastern region and the eastern region is gradually widening. The period from 2013 to 2017 was the period of accelerated expansion of differences. After 2013, the Gini coefficient of the eastern and western regions increased notably, reaching a peak of 0.2707 in 2016, which is closely related to the rapid rise of emerging industries and the vigorous development of the digital economy in the eastern region, while the western region is constrained by geographical conditions and resource endowments, and the talent attraction is relatively insufficient. At the same time, the difference between the northeast and the east also intensified during this period, with the Gini coefficient jumping to 0.2183 in 2013, reflecting the further highlighting of the difficulties faced by the northeast region in the process of transformation and upgrading. The period from 2018 to 2022 is the stage of slow convergence of differences. After the implementation of the Rural Revitalization Strategy in 2017, the policy effect gradually emerged, and the difference between the east and the west began to decline slowly, falling to 0.2156 in 2022. The differences between the central and western regions and the northeast and the western regions also showed a continuous downward trend, indicating that the regional coordinated development strategy and targeted poverty alleviation policies have achieved certain results in promoting the revitalization of talents in the central and western regions and the northeast region. However, the gap between the east and the northeast is still widening, reaching 0.2017 in 2022, suggesting that the revitalization of talent in the northeast still needs more targeted policy support.

In summary, the eastern region presents a "dual-core drive" effect, and its high-level balanced development (such as the Yangtze River Delta and Pearl River Delta urban agglomerations) makes it always in a dominant position in the regional differences. The difference between the eastern and western regions has been running at a high level for a long time, reflecting that the "siphon effect" of the eastern region on the talents in the western region is still significant. The slight decline in the difference between the eastern and central regions may be related to the fact that the central region undertakes the transfer of industries from the eastern region and promotes the return of talents. The northeast region is facing the dilemma of "marginalization", and the gap between the northeast and the east continues to widen, indicating that the marginalization trend of the northeast region in the eastern economic circle is intensifying. Although the difference between the northeast and the west has narrowed remarkably, this is more due to the rapid development of the western region than to the pronounced improvement of the revitalization level of the northeast itself. The U-shaped trend of the coefficient comparing the northeast and the central region further confirms the embarrassing position of the northeast region in regional coordination. The central region plays the role of a "bridge". The difference between the central and western regions has decreased significantly, reflecting the increasing pivotal role of the central region in connecting the revitalization and development of rural talents in the eastern and western regions. By undertaking the industrial transfer from the eastern region and promoting agricultural modernization, the central region has provided personnel and technical support for the western region and promoted balanced development among regions. The western region is in a "catch-up" trend. In particular, the Gini coefficient comparing the western region and northeastern regions has decreased from 0.0789 in 2008 to 0.0408 in 2022, a decrease of 48.3%, indicating that the western region has achieved rapid development with policy support. However, the differences between the western region and the eastern region are still prominent, suggesting that the western region still needs to increase investment in infrastructure and industrial upgrading.

(3) Sources of Differences and their Contributions

Through the decomposition and analysis of the sources of differences in the level of rural talent revitalization from 2008 to 2022, it can be found that the composition and evolution of regional differences show significant regularity characteristics, as shown in Figure 4.2.

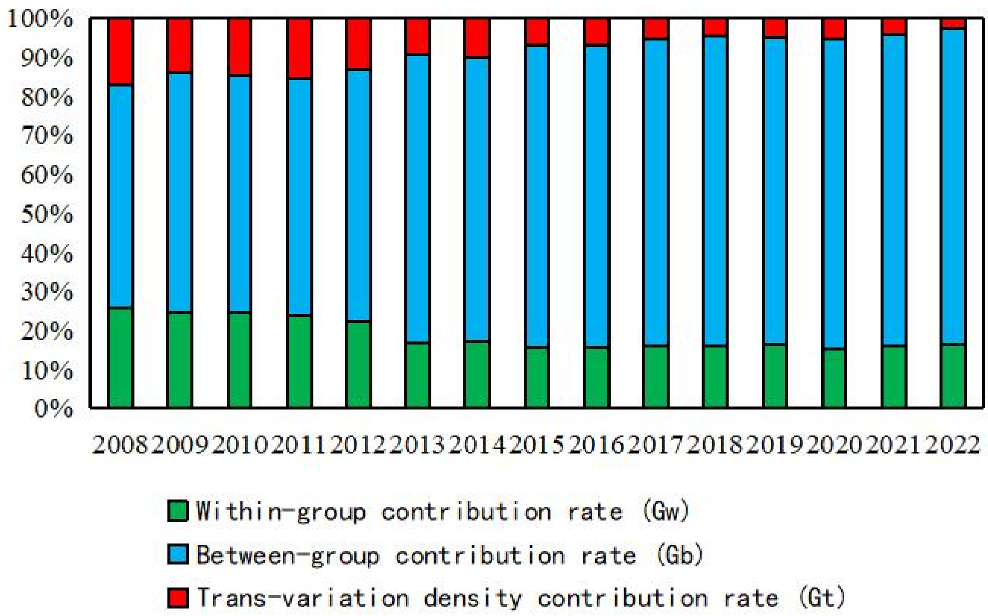

Figure 4.2: Decomposition results of the Gini coefficient of rural talent revitalization

Overall, the difference between groups has always been the main source of the difference in the level of rural talent revitalization, and its contribution rate has continued to increase from 56.86% in 2008 to 80.95% in 2022, with an average annual growth rate of 1.6 percentage points, indicating that the problem of regional imbalance has been increasing during the study period. At the same time, the contribution rate of intra-group differences fluctuated from 25.81% in 2008 to 16.46% in 2022, and although the decrease was relatively obvious, its contribution rate remained above 15%, indicating that the problem of intra-regional development imbalance still exists and has not been completely alleviated by the expansion of inter-regional differences. The contribution rate of supervariable density decreased significantly from 17.33% in 2008 to 2.59% in 2022, reflecting the gradual reduction of barriers to inter-regional factor flow and the improvement of conditions for regional coordinated development.

The continuous expansion of the differences between groups is the core feature of the evolution of the differences in the level of rural talent revitalization. In 2022, the inter-group contribution rate reached 80.95%, which was 4.9 times that of the intra-group contribution rate, compared to 2.2 times in 2008, indicating that the dominance of inter-group differences was further strengthened during the study period. This trend is closely related to the strengthening of the economic agglomeration effect in the eastern region, which continues to attract high-quality talents by virtue of its strong economic strength and innovation advantages, while the northeast and western regions are relatively insufficient in talent attraction due to factors such as single industrial structure and lagging infrastructure, resulting in widening regional differences. Although the policy effect gradually emerged after the implementation of the Rural Revitalization Strategy in 2017, and the differences between the east and the west began to decline slowly, the contribution rate between the groups remained at a high level of about 80%, indicating that the deep-seated contradictions between regions have not been fundamentally alleviated. The significant shrinkage of the supervariable density contribution rate requires special attention. In 2008, the contribution rate of supervariable density was 17.33%, and by 2022, it has decreased to 2.59%. This change reflects the gradual reduction of barriers to the flow of factors between regions, and the improvement of conditions for regional coordinated development. However, the shrinkage of the contribution rate of supervariable density did not reverse the dominance of inter-group differences, but highlighted the solidification trend of inter-regional differences. In particular, during the period from 2013 to 2018, the contribution rate of supervariable density dropped sharply from 14.79% to 5.34%, which was in sharp contrast to the rapid increase in the contribution rate between groups, indicating that the expansion of inter-regional differences was more due to the rapid development of the eastern region than the lack of inter-regional element flow. The evolution of intra-group differences showed a strong "resilience". Although the contribution rate within the group decreased from 25.81% in 2008 to 16.46% in 2022, its contribution rate remained above 15%, indicating that the problem of uneven development within the region is still prominent. For example, the differences between coastal and inland areas in the eastern region, and between provincial capitals and remote areas in the western region, may become important factors restricting the revitalization of rural talents. This "resilience" characteristic shows that even in the context of regional differences, balanced development within a region cannot be ignored.

In general, the source composition and evolution of the difference in the level of rural talent revitalization not only reflect the strengthening of the economic agglomeration effect between regions, but also reveal the deep-seated contradiction of unbalanced development within the region. In the future, policy design needs to focus on the balanced development within the region while solving the differences between regions, and promote the overall improvement of the revitalization level of rural talents by optimizing the factor flow mechanism and strengthening regional coordination policies.

4.1.2. Temporal Evolution of Rural Talent Revitalization

Based on the analysis of regional differences in rural talent revitalization based on the Gini coefficient, although the characteristics of relative differences can be effectively revealed, it is difficult to capture the spatiotemporal evolution trajectory of absolute differences. In order to break through the limitations of this method, the nonparametric kernel density estimation (KDE) method was introduced in this study, and the convolutional kernel function was used to provide a smooth estimate of the distribution, systematically describe the distribution position shift, morphological evolution and tail extension characteristics of the talent revitalization index. Based on the kernel density curve generated by the MATLAB 2022 platform, the dynamic convergence or divergence trend of the rural talent revitalization level is deconstructed from the dual dimensions of the national macro pattern and the mesoscale of the four major economic zones.

Compared with the relative difference characterization of the Gini coefficient, kernel density estimation, through the non-parametric fitting of the probability density function, can not only retain the original shape information of the data distribution, but also avoid the detail loss caused by the setting of grouping intervals in histogram analysis (Weglarczyk, 2018). Its application value lies in being able to reveal the overall migration of the development level through the spatial displacement of the density peak, reflect the absolute fluctuation of regional differences through the change of the peak width, and identify the spatial agglomeration law of extreme values through the distribution tailing characteristics. This multi-dimensional analytical ability provides a more refined observation tool for revealing the gradient evolution and spatial polarization phenomena of rural talent revitalization. The specific formula is:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x_i - x}{h}\right) . \quad (4.8)$$

In equation (4.8), $f(x)$ represents the estimated probability density function of the rural talent revitalization index, n is the number of observations, k is the kernel function, x_i is the observed value of the rural talent revitalization Index for the i-th province, and the commonly used kernel functions include the Gaussian kernel function, trigonometric kernel function, double-weight kernel function, etc., and the Gaussian kernel function is selected for estimation in this study. The bandwidth h determines a trade-off: a larger value increases the smoothness of the estimated density curve at the expense of estimation accuracy. In the actual estimation process, a smaller bandwidth should be selected as much as possible to improve the estimation accuracy, 0.03 was selected as the bandwidth in this study, and the data analysis and graphical drawing were carried out by Matlab 2022.

(1) At the National Level

Figure 4.3 shows the dynamic evolution of the estimated distribution of rural talent revitalization in China from 2008 to 2022.

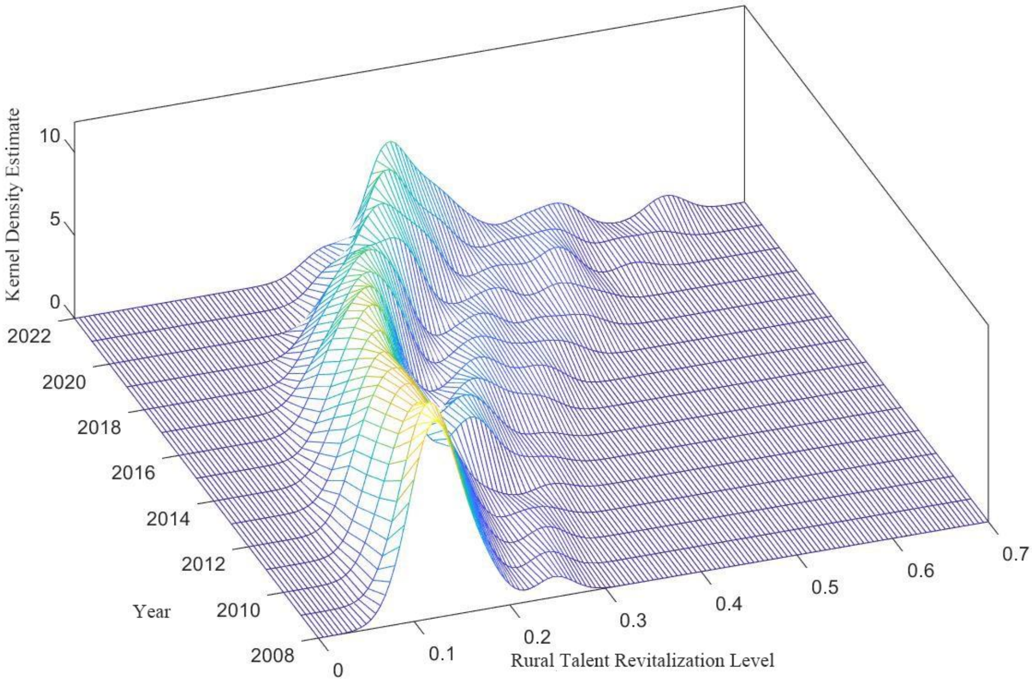

Figure 4.3: Kernel density estimation curve of the National Rural Talent Revitalization Index

From the perspective of the overall change of the kernel density curve, the level of rural talent revitalization shows a significant rightward shift over time. In 2008, the main peak position was roughly between 0.1 and 0.2, and in 2022, the main peak position moved to the right to the range of 0.3 to 0.4, indicating that the level of rural talent revitalization in China has been systematically improved during the study period. This trend is consistent with the previous level measures. There is an obvious right tailing phenomenon in the kernel density curve, and the distribution pattern of tailing tends to diverge with the passage of time, indicating that the gap in the level of rural talent revitalization in different regions is further widened. Specifically, high-level regions (such as Beijing, Shanghai, Zhejiang, and other eastern coastal provinces) continue to widen the absolute gap with other regions by virtue of their economic agglomeration advantages and policy dividends, while low-level regions (such as some western provinces) are subject to geographical conditions, industrial structure and other factors, and their development is relatively lagging behind, resulting in a solidification trend of regional differences. The widening of this gap is closely related to the weak inter-regional economic ties and the limited flow of factors, especially during the period from 2013 to 2018, when the rapid development of rural e-commerce and smart agriculture in the eastern region further exacerbated the regional imbalance. From the morphological changes of the kernel density curve, the height of the main peak showed the characteristics of "first decreasing and then rising", and the peak width showed "first wide and then narrow". From 2008 to 2014, the height of the main peak decreased and the peak width expanded, indicating that the absolute difference between regions expanded. It is worth noting that after 2020, increasingly pronounced side peaks have emerged on the kernel density curve,, suggesting that the level of rural talent revitalization has been multipolarized, and the challenge of inter-regional coordinated development is still severe. Overall, the dynamic evolution of the kernel density curve reveals the deep-seated characteristics of "overall improvement, solidification of differences, and multi-polarization" of the level of rural talent revitalization in China.

(2) Regional Level

As shown in Figure 4.4, the position of the main peak of the kernel density curve in the eastern region has shifted significantly to the right from about 0.15 in 2008 to about 0.5 in 2022, indicating that the level of rural talent revitalization in the eastern region has been significantly improved during the study period. This change is closely related to the rapid economic development, the abundance of high-level human resources, and the greater policy support in the eastern region. The morphology of the kernel density curve gradually shifted to the right from the early bimodal distribution, and the tail diverged significantly, indicating the imbalance of development in the eastern region. This imbalance is mainly due to the fact that the leading edge of a few high-level regions (such as the Yangtze River Delta and the Pearl River Delta) is still significant, resulting in the persistence of intra-regional disparities. Between 2008 and 2014, the peak of the curve gradually decreased and the peak width increased, further reflecting the widening of intra-regional differences. This phenomenon may be related to the rapid economic rise of the eastern coastal areas, while the development of some inland cities is relatively lagging behind. After 2014, the position and distribution width of the main peaks tended to be stable, marking that the differences within the region entered a relatively stable stage. However, the multimodal structure has not disappeared, but has taken on a more complex pattern in the later stages (especially after 2020), suggesting that new growth poles or differentiation patterns are taking shape in the region. Meanwhile, the agglomeration effect of high-level areas is still significant, suggesting that the balanced development of the eastern region needs to be further promoted. During the whole investigation period, the kernel density curve showed a multimodal phenomenon, and the internal polarization phenomenon of the region was significant. The level of rural talent revitalization in the eastern region has been significantly improved, but the problem of solidification of internal differences cannot be ignored.

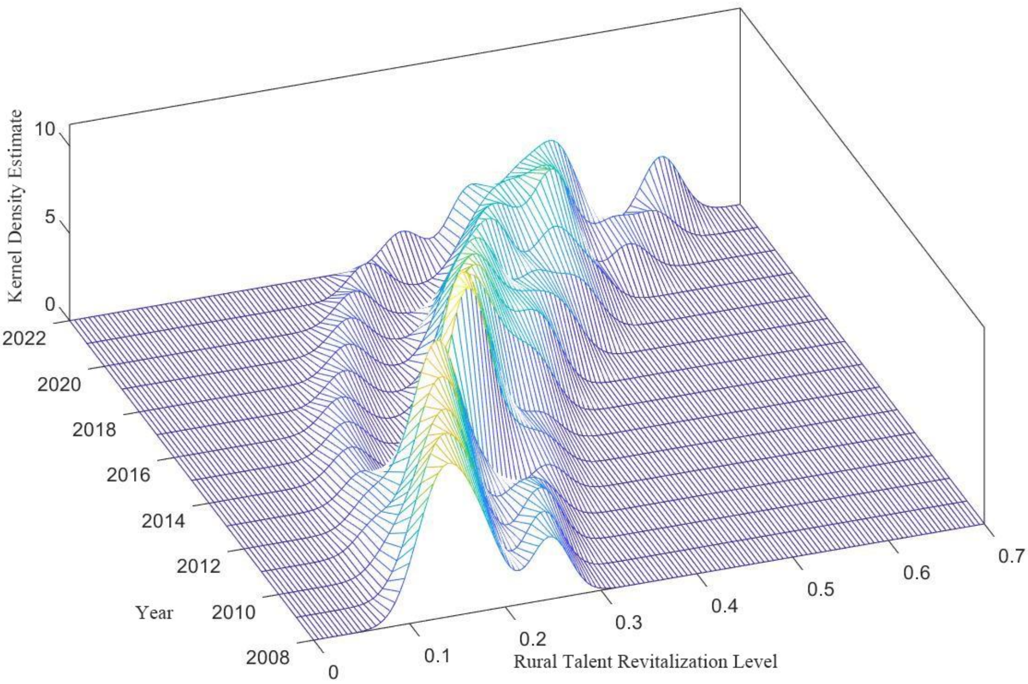

Figure 4.4: Kernel density estimation curve of the Eastern Rural Talent Revitalization Index

As shown in Figure 4.5, the position of the main peak of the kernel density curve in the central region has shifted significantly to the right from around 0.15 in 2008 to about 0.37 in 2022, indicating that the level of rural talent revitalization in the central region has achieved a steady improvement during the study period. This change is closely related to the in-depth implementation of the strategy of the rise of the central region, the development opportunities brought about by the gradient transfer of industries, and the continuous improvement of infrastructure. Especially after 2016, with the acceleration of the transfer of industries from the eastern region to the central region, the central region has gradually improved the talent introduction and training mechanism while undertaking industrial transfer, and promoted the overall improvement of the level of rural talent revitalization. From the perspective of the change of curve morphology, the kernel density curve gradually became symmetrical from the early right-biased distribution, indicating that the development imbalance in the central region has been alleviated. The distribution pattern of the curve in 2022 is more concentrated, and the peak width is significantly narrower than that in 2008, indicating that the equilibrium within the region has been enhanced. This change is inseparable from the continuous investment in transportation infrastructure and the balanced allocation of educational resources in the central region. For example, the improvement of the high-speed rail network and the promotion of the policy of integrating urban and rural education have effectively promoted the inter-regional flow and balanced distribution of human resources. Between 2008 and 2014, the peak of the curve gradually decreased and the peak width increased, reflecting a widening of intra-regional differences. After 2014, the peak value of the curve tended to be stable, and the peak width did not change much, indicating that the intra-regional differences had entered a relatively stable stage. At the same time, the right tail of the curve gradually shortened and the left tail became longer, suggesting that the pull effect of the high-level region on the overall distribution was weakened, and the synergy within the region was further enhanced. During the whole investigation period, the kernel density curve always showed a unimodal phenomenon, indicating that the internal development of the central region had good synergy and no obvious polarization phenomenon. This unimodal distribution is closely related to the central region as a hub connecting the east and west, which not only benefits from the technology spillover of the eastern region, but also forms a certain radiation driving effect on the western region. The improvement of the level of rural talent revitalization in the central region is driven by the dual drive of policy support and industrial transfer, and the balance within the region has gradually increased. However, some resource-based and agriculture-dominated regions still face challenges such as brain drain and single industrial structure.

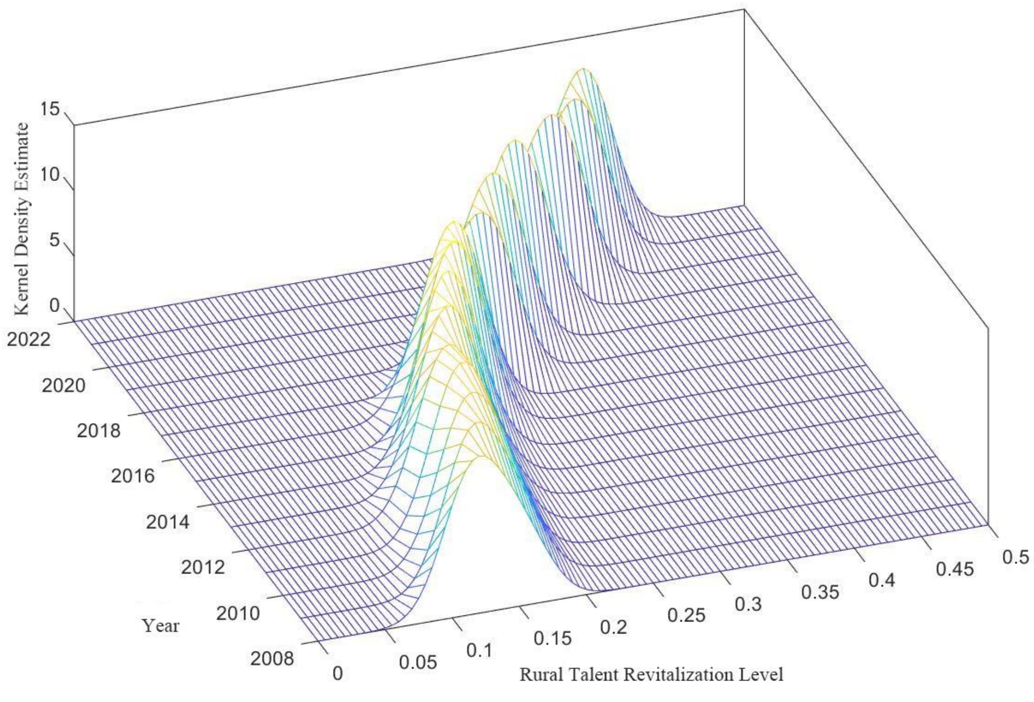

Figure 4.5: Kernel density estimation curve of the Central Rural Talent Revitalization Index

As shown in Figure 4.6, the main peak of the rural talent revitalization index distribution curve in the western region has shifted to the right as a whole, gradually moving to the right from around 0.1 in 2008 to about 0.34 in 2022, indicating that the level of rural talent revitalization in the western region has been significantly

improved during the study period. This change is closely related to the continuous advancement of the strategy of large-scale development of the western region, the continuous improvement of infrastructure, and the effective implementation of targeted poverty alleviation policies. From the perspective of the morphological change of the kernel density curve, the height of the main peak showed the characteristics of "first decreasing, then rising and then decreasing", and the peak width showed an evolutionary trend of "first widening, then narrowing, and then widening". Specifically, from 2008 to 2016, the height of the main peak decreased and the peak width expanded, reflecting the expansion of intra-regional differences, which may be related to the fact that some provinces (e.g., Chongqing and Shaanxi) took the lead in development by virtue of their geographical advantages and policy dividends, while other regions (e.g., Tibet and Yunnan) lagged behind due to geographical conditions and industrial structure. From 2017 to 2022, the height of the main peak rebounded and the peak width narrowed, indicating that the differences within the region gradually narrowed. To a certain extent, in the later years the kernel density curve has a left-tailing phenomenon, which is mainly due to the heterogeneity of geographical conditions, industrial structure and development foundation. Throughout the study period, the kernel density curve always showed a predominantly unimodal phenomenon, indicating that there was no serious polarization in the western region. This unimodal distribution is closely related to the overall development of the western region under policy support, and also reflects the gradual enhancement of synergy within the region. It is noteworthy, however, that the curve for 2022 may suggest a potential shift in this structure, warranting future attention.
Concurrently, the persistence of the left-tailing phenomenon suggests that the catch-up path in low-level areas still needs to be further optimized.

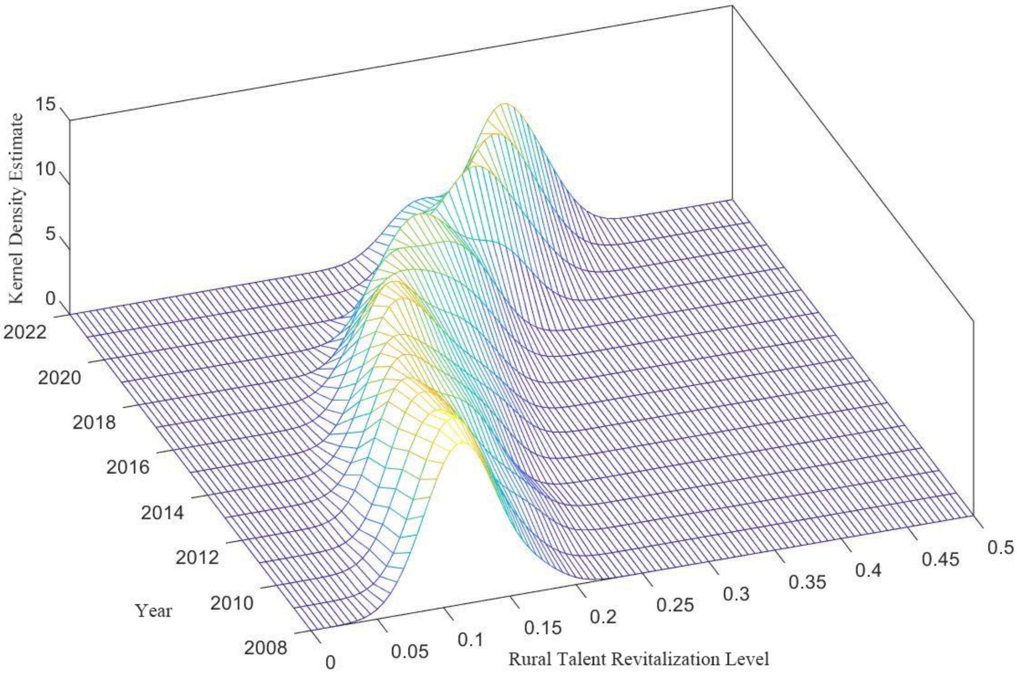

Figure 4.6: Kernel density estimation curve of the Western Rural Talent Revitalization Index

As illustrated in Figure 4.7, the kernel density distribution of rural talent revitalization in northeast China demonstrates a resemblance to the pattern observed in the western region, both regions exhibiting relatively low development levels and a delayed progression trajectory compared to their eastern and central counterparts. The position of the main peak shifted from approximately 0.15 in 2008 to 0.35 in 2022, signifying that although rural talent revitalization in northeast China has experienced improvement during the study period, its absolute level remains substantially lower than that of more developed regions. From the perspective of morphological evolution, the height of the main peak showed the characteristics of "continuously rising", and the peak width exhibited an evolutionary trend of "gradually narrowing", indicating that the intra-regional differences have been continuously diminishing alongside the overall improvement in rural talent revitalization levels. The kernel density curve transformed from a pronounced right-skewed distribution in 2008, characterized by an extended right tail, to a substantially more symmetric configuration by 2022. This transformation suggests that the intra-regional development disparity in northeast

China has been notably mitigated, with previously underperforming areas demonstrating accelerated catch-up growth.

It is noteworthy that the kernel density curve in northeast China consistently maintained a predominantly unimodal phenomenon throughout the study period, indicating that no serious polarization occurred within the region. This unimodal distribution is closely related to the coordinated development of various provinces under policy support, and also reflects the gradual enhancement of synergy within the region. However, compared with other regions, particularly the eastern region where development levels are significantly higher, the improvement in northeast China is relatively modest, suggesting that it still faces considerable challenges in the process of rural revitalization. This phenomenon may be closely related to the persistent difficulties in traditional industrial transformation, continuous population outflow, and insufficient economic vitality in northeast China.

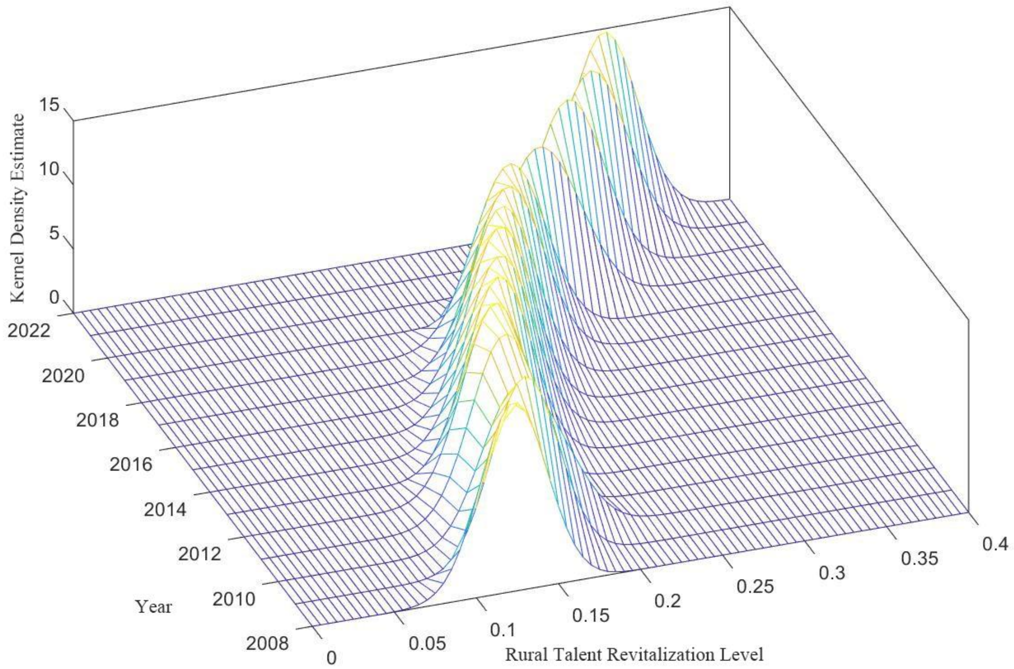

Figure 4.7: Kernel density estimation curve of the Northeast Rural Talent Revitalization Index

4.2. Spatial Correlation and Agglomeration Evolution Analysis

Spatial correlation analysis aims to deeply explore the interrelationship and dependence between spatial data, and shows high application value in multiple fields. The core of spatial correlation analysis is to accurately measure the similarities or differences between spatial units, and indicators such as the Global Moran's I and Local Moran's I provide effective quantitative means for this (Bivand et al., 2018). Through spatial correlation analysis, we can clearly understand the spatial distribution pattern of rural talent revitalization level in different regions. Based on the results of spatial correlation analysis, the government and relevant departments can formulate and adjust the rural talent revitalization policy more scientifically. For areas with high values of the Rural Talent Revitalization Index, the successful experiences can be further summarized and consider how to extend these experiences to other regions. For low-value clusters, it is necessary to deeply analyse the existing problems and constraints, and formulate more targeted support policies. Adjacent or geographically similar regions may have certain connections and interactions in the revitalization of rural talents. Through the analysis, it is possible to identify which regions have strong spatial synergies, and then promote cooperation and exchanges between these regions, realize resource sharing, complement each other's advantages, and jointly promote the revitalization of rural talents. At the same time, it will also help to break the restrictions of administrative divisions, formulate a coordinated development strategy from the perspective of overall regional development, and form a joint force for the revitalization of rural talents.

4.2.1. Spatial Correlation Analysis

The global Moran index is mainly used to evaluate the spatial autocorrelation of the entire study area, that is, to grasp the degree of aggregation or dispersion of spatial data as a whole, and its calculation formula is as follows:

$$I = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{W\sum_{i=1}^{N}(x_i-\bar{x})^2} \quad . \tag{4.9}$$

where N is the number of space cells, and x_i is the observed value of the first space unit. w_{ij} is the spatial weight matrix element, $w_{ij} = 1$ if regions i and j are adjacent, otherwise $w_{ij} = 0$. W is the sum of all the w_{ij}. The value of Moran's I typically ranges from -1 to 1. A significantly positive I (e.g., $I > 0$) indicates positive spatial autocorrelation (clustering of similar values, high-high or low-low). A significantly negative I (e.g., $I < 0$) indicates negative spatial autocorrelation (a checkerboard pattern of dissimilar values). An I value near 0 suggests a spatially random pattern. The statistical significance of Moran's I is tested using a Z-score: $Z = \frac{I-E(I)}{\sqrt{Var(I)}}$, where $E(I)$ is the theoretical expected value of I under the null hypothesis of spatial randomness, and $Var(I)$ is its standard deviation. The corresponding p -value determines whether the observed spatial pattern is statistically significant.

In order to further explore the spatial distribution characteristics and dynamic trend of rural talent revitalization in China, this study was based on the data of the rural talent revitalization index from 2008 to 2022 and used the global Moran's I index to analyse. The results of global spatial autocorrelation analysis based on the spatial adjacency matrix are shown in Table 4.2. From 2008 to 2022, the rural talent revitalization index in China showed significant spatial agglomeration characteristics. The results of the Moran's I index test showed that the null hypothesis of a spatial random distribution (Z value >2.58 which is the critical value of the standard normal distribution at the 99% confidence level, p<0.001) was rejected at the significance level of 1% during the study period), which confirmed that the rural talent revitalization index of China did not show a random spatial distribution pattern during the study period. Rather, it has a significant positive spatial autocorrelation in the Moran's I range (the observed range was 0.3363 to 0.5632).

From the perspective of time series evolution, the global Moran's I index showed a notable upward trend, from 0.3363 in 2008 to 0.5502 in 2022, an increase of 63.54%.

This trend reveals two important characteristics: First, the spatial dependence of the level of rural talent revitalization between provinces continues to increase, and the geographical proximity shows significant spatial spillover effects and linkage development characteristics. Second, the regional coordinated development mechanism has been gradually strengthened, and the interaction between neighboring provinces in the allocation of talent factors and policy transmission mechanisms has become increasingly close. It is worth noting that the Moran's I Index has maintained a high level of volatility after breaking through the 0.5 threshold in 2015, reflecting the spatial integration effect of the regional coordinated development policy system since the 13th Five-Year Plan.

Table 4.2: Moran's I Index of China's Rural Talent Revitalization Level and tests of significance from 2008 to 2022

Year	I	E(I)	Sd(I)	Z	P-value
2008	0.3363	-0.0333	0.1124	3.2873	<0.001
2009	0.3435	-0.0333	0.1123	3.3555	<0.001
2010	0.3504	-0.0333	0.1137	3.3736	<0.001
2011	0.3796	-0.0333	0.1136	3.6338	<0.001
2012	0.4395	-0.0333	0.1123	4.2093	<0.001
2013	0.4945	-0.0333	0.1186	4.4512	<0.001
2014	0.4975	-0.0333	0.1187	4.4721	<0.001
2015	0.5006	-0.0333	0.1192	4.4812	<0.001
2016	0.5360	-0.0333	0.1191	4.7789	<0.001
2017	0.5470	-0.0333	0.1188	4.8830	<0.001
2018	0.5459	-0.0333	0.1184	4.8930	<0.001
2019	0.5255	-0.0333	0.1187	4.7057	<0.001
2020	0.5622	-0.0333	0.1184	5.0280	<0.001
2021	0.5632	-0.0333	0.1176	5.0712	<0.001
2022	0.5502	-0.0333	0.1167	5.0018	<0.001

The dynamic evolution characteristics of spatial correlation show that there is an obvious convergence phenomenon of spatial clusters in the revitalization of rural talents at the provincial level in China. In particular, the implementation of the main functional area planning, the establishment of cross-regional talent cooperation mechanisms and the acceleration of the equalization process of basic public services have effectively promoted the optimal allocation and coordinated development of talent elements among neighboring provinces. The results of this study confirm the gradual emergence of regional synergies in the implementation of the rural talent revitalization strategy from the perspective of spatial measurement.

Furthermore, based on the theory of spatial econometrics, the spatial correlation characteristics of rural talent revitalization are tested by constructing a spatial geographic distance matrix and a spatial economic distance matrix to avoid the risk of model misdesign that may arise from a single matrix. The spatial geographic distance matrix breaks through the traditional adjacency limitation, calculates the longitude and latitude coordinates of the geographic centroid of each province based on ArcGIS, and constructs a continuous spatial association network through the inverse distance squared weighting algorithm. Based on the theory of economic similarity (Ertur et al., 2007), the spatial economic distance matrix constructs the weight based on the difference in per capita GDP, and represents the economic gradient correlation through the reciprocal of the difference, so that provinces with similar economic levels get higher weights.

The results are shown in Table 4.3. From 2008 to 2022, the global Moran's I indices under the two spatial weight matrices both pass the significance test at the 1% level ($p < 0.001$), confirming the robustness of the spatial dependence of rural talent revitalization. Among them, the Moran's I index of the geographical adjacency matrix is noticeably higher than that of the geographical distance matrix (0.128-0.141) and the economic distance matrix (0.280-0.322), revealing that spatial correlation strength is strongest for shared borders, then for economic similarity, and weakest for pure geographical distance, which embodies a distance decay effect. Although there are differences in the absolute values of Moran's I of the three matrices, the significance level remains stable during the full sample period (Z > 2.58), proving that the spatial dependence of rural talent revitalization is robust and is not fundamentally affected by the form of weight setting.

Table 4.3: Global Moran's I index of rural talent revitalization level in China under different spatial matrices

Year	Spatial Geographic Distance Matrix				Spatial Economic Distance Matrix			
	I	Sd(I)	Z	P-value	I	Sd(I)	Z	P-value
2008	0.128	0.033	4.920	<0.001	0.280	0.086	3.641	<0.001
2009	0.137	0.033	5.198	<0.001	0.290	0.086	3.764	<0.001
2010	0.139	0.033	5.192	<0.001	0.292	0.087	3.734	<0.001
2011	0.150	0.033	5.525	<0.001	0.302	0.087	3.856	<0.001
2012	0.158	0.033	5.838	<0.001	0.316	0.086	4.056	<0.001
2013	0.148	0.035	5.251	<0.001	0.371	0.091	4.452	<0.001
2014	0.155	0.035	5.440	<0.001	0.379	0.091	4.535	<0.001
2015	0.143	0.035	5.084	<0.001	0.374	0.091	4.457	<0.001
2016	0.151	0.035	5.290	<0.001	0.385	0.091	4.586	<0.001
2017	0.150	0.035	5.273	<0.001	0.355	0.091	4.262	<0.001
2018	0.147	0.035	5.218	<0.001	0.337	0.091	4.085	<0.001
2019	0.142	0.035	5.060	<0.001	0.313	0.091	3.808	<0.001
2020	0.161	0.035	5.609	<0.001	0.323	0.091	3.931	<0.001
2021	0.157	0.034	5.552	<0.001	0.327	0.090	3.996	<0.001
2022	0.141	0.034	5.132	<0.001	0.322	0.089	3.973	<0.001

4.2.2. Spatial Agglomeration Evolution Analysis

Exploratory Spatial Data Analysis (ESDA), as the core tool of the geospatial measurement system, systematically reveals the distribution patterns, structural characteristics and spatial interaction mechanisms of geographic elements by integrating spatial autocorrelation and hotspot detection technologies (Percival et al., 2022). In this study, the local Moran's I index was used to deconstruct the spatial correlation characteristics of China's rural talent revitalization index.

Although the global Moran's I index can determine the existence of global spatial autocorrelation, it cannot reveal the pattern of local heterogeneity. To solve this problem, the local Moran's I index is introduced to construct a spatial correlation matrix, which is calculated as follows:

$$Local\ Moran's\ I = \frac{N(x_i-\bar{x})}{\sum_{i=1}^{N}(x_i-\bar{x})^2}\sum_{j=1}^{N} w_{ij}(x_j-\bar{x})^2. \tag{4.10}$$

Through STATA 17, the local Moran scatter plots of the Rural Talent Revitalization Level in 2008, 2015, and 2022 were plotted, as shown in Figure 4.8. The 31 provinces were mapped to four characteristic quadrants, the abscissa was the standardized value of the Rural Talent Revitalization Index in each year, the vertical axis was the spatial lag value, the red line represented the Tropic of Cancer, and the blue dots represented the 31 study areas. Type H-H (first quadrant) indicates that high values are surrounded by high values, forming a development highland; The L-L type (third quadrant) indicates that the low values are surrounded by the low values, constituting a lag depression; Type H-L (fourth quadrant) indicates high values surrounded by low values, indicating an islanding effect; Type L-H (second quadrant) indicates that low values are surrounded by high values, indicating a depression breakout.

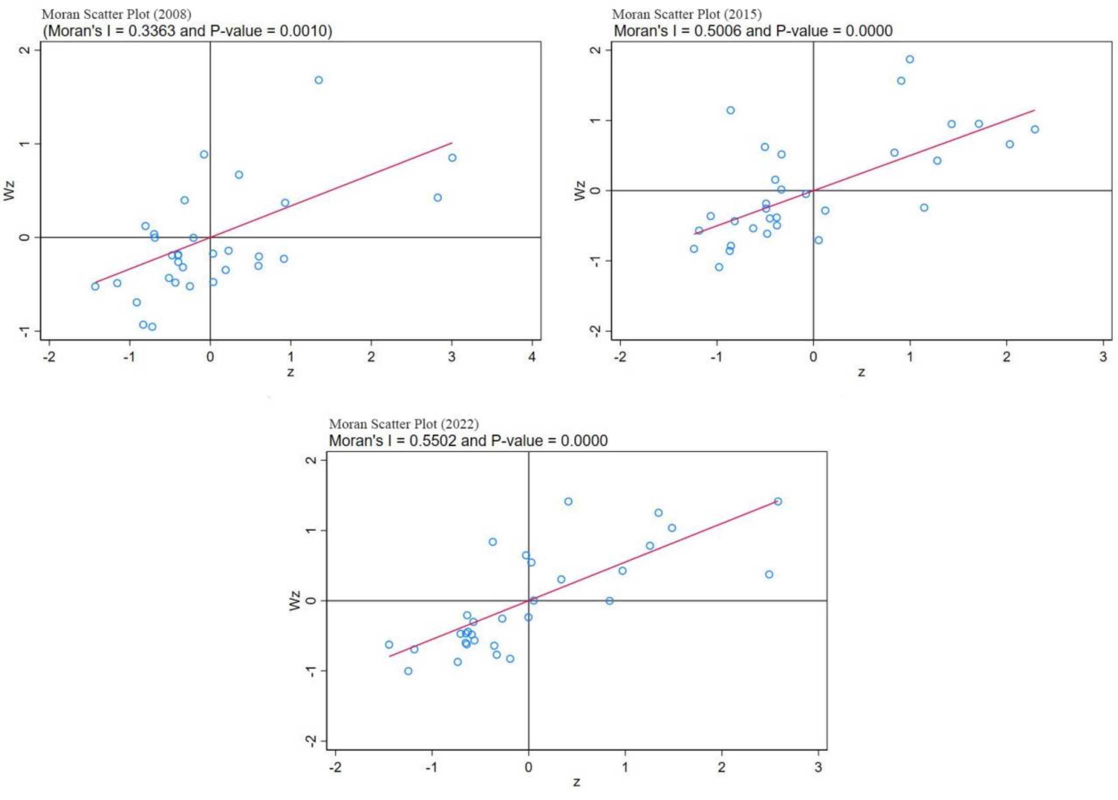

Figure 4.8: Local Moran scatter plots of rural talent revitalization (2008, 2015 and 2022)

Note: The spatial matrix is the spatial geographic adjacency matrix. z stands for the deviation vector (i.e. $x_j - \bar{x}$), W_z stands for the spatial lag vector (i.e. $(x_i - \bar{x})^2$).

The spatiotemporal evolution analysis based on the Moran scatter plot shows that the spatial agglomeration pattern of rural talent revitalization in China shows significant dynamic reconstruction characteristics, and forms a deep coupling with regional development strategies. On the whole, the provinces are mainly concentrated in the H-H and L-L quadrants, showing significant spatial cluster convergence characteristics. The existence of H-L and L-H outliers reveals the gradient fracture phenomenon in regional synergistic development. From the perspective of the spatial correlation model, the high-altitude (H-H) agglomeration area continues to expand, from the Beijing-Tianjin-Hebei region and the five core provinces (cities) of the Yangtze River Delta in 2008 to gradually absorb Jiangsu, Fujian, Shandong, Jiangxi, Henan and other provinces, and by 2022, a contiguous high-value cluster of 10 provinces across the eastern coast and the hinterland of the Central Plains will be formed, which confirms the cross-regional synergy effect of talent elements under the "urban agglomeration-economic belt" strategy. This diffusion path is highly consistent with the spatial deployment of the Yangtze River Economic Belt and the Beijing-Tianjin-Hebei coordinated development plan, especially the accession of central provinces such as Henan and Jiangxi, revealing that the "rise of central China" policy promotes the extension of the radiation scope of high-value provinces to the provinces inland through infrastructure interconnection and industrial gradient transfer. Meanwhile, the agglomeration areas of the low - low (L - L) type expanded from 15 provinces in 2008 to 18 provinces in 2022. Their spatial scope continuously spread toward the northwest and northeast directions. The continuous locking - in of border provinces such as Inner Mongolia, Qinghai, and Xinjiang, as well as the overall decline of the three northeastern provinces, highlight the systematic dilemmas in talent attraction and retention mechanisms in the regions to the west of the "Hu

Huanyong Line". This "cold pole effect" and the differentiation of the regional economy, as well as the non - equalization of public services, form a vicious cycle.

From the observation of the evolution of outliers, the number of high-low and low-type (H-L) provinces has decreased sharply from 7 in 2008 to only Guangdong in 2022, and this phenomenon of "islandization" reflects the development fault line between the Pearl River Delta region and its surrounding provinces. Although Guangdong has formed a talent highland with the first-mover advantage of reform and opening up, it has failed to effectively promote the coordinated improvement of neighboring provinces such as Guangxi, Hunan and Jiangxi, reflecting the lack of cross-provincial talent cooperation mechanism. The number of low-high-level (L-H) provinces has shrunk from 4 in 2008 to 2 (Anhui and Hainan) in 2022 and especially the original low-high and high-level provinces such as Jiangsu and Fujian have been upgraded to high-value zone members, indicating that the "neighbor-driven" effect has gradually taken effect in strategic areas such as the Yangtze River Delta and the economic zone on the west coast of the Taiwan Strait. It is worth noting that in 2022, Xinjiang is added to the low-level agglomeration area, while Tibet continues to be in a low-value lock-in state, which is not only related to the objective conditions such as the natural environment constraints and the single industrial structure in the border areas, but also exposes the limitations of the policy of Xinjiang aid to Tibet and Xinjiang in stimulating endogenous power.

This evolutionary trajectory of the coexistence of spatial polarization and diffusion is essentially the result of the combined effect of market mechanisms and policy interventions. The expansion of high-value clusters benefits from the spatial compression effect brought about by the high-speed rail network and digital technology, which accelerates the reallocation of talents in core provinces. The solidification of low-value areas reveals the deep contradiction between "resource curse" and "path dependence", especially when resource-based provinces are facing the pain of transformation of traditional industries, and the brain drain and lack of innovation form a two-way block. The results warn from the perspective of spatial differentiation that it is necessary to establish a differentiated regional talent governance system, and to focus on improving the "revolving door" mechanism of regional talent flow in high-value contiguous areas to prevent the congestion effect caused by excessive agglomeration. For the isolated highland, it is necessary to strengthen the integration of cross-administrative industrial chains and cultivate a regional talent ecosystem. For low-value subsidence areas, it is necessary to innovate the "enclave economy" model and break down spatial barriers through institutional knowledge transfer.

4.3. Analysis of Spatiotemporal Evolution Trends

4.3.1. Spatiotemporal Directional Evolution Analysis

The spatial distribution characteristics and dynamic evolution trajectory of the rural talent revitalization level are important perspectives for understanding the changes in the regional development pattern. This study adopts the standard deviation ellipse method(Lefever, 1926) to quantitatively analyse the spatial directionality and dispersion degree of the rural talent revitalization index of 31 provinces across the country from 2008 to 2022, aiming to reveal the migration path of its distribution centre of gravity and the change law of the diffusion mode. By calculating the average centre, distribution direction, and dispersion range of spatial data, the standard deviation ellipse can intuitively depict the agglomeration trend and spatial expansion characteristics of geographical elements. The coordinate of the ellipse centre represents the centre - of - gravity position of the spatial distribution of rural talent revitalization, and the deviation of its longitude and latitude reflects the migration trajectory of the regional development core; the direction of the long axis indicates the extension direction of the main trend of the spatial distribution, and the change of the rotation angle reveals the turning characteristics of the regional development kinetic energy; the lengths of the long axis and the short axis respectively measure the dispersion degree of the data along the primary and secondary directions, and their ratio (flat rate) can quantify the evolution of the equilibrium of the spatial distribution. The specific calculation steps are as follows (Zhang et al., 2022):

Step 1: Calculate the ellipse centre $(\bar{x}, \bar{y})$, determined by the weighted average of the coordinates of all spatial units, with a weight of the Talent Revitalization Index of each province.

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} , \tag{4.12}$$

$$\bar{y} = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} . \tag{4.13}$$

Where x_i, y_i are the geographic coordinates (e.g., longitude and latitude of the provincial capital) of province i. w_i is the weight assigned to province i, represented by its rural talent revitalization index.

Step 2: The covariance matrix eigenvalue decomposition is obtained, and the direction angle θ represents the main trend direction of the data distribution.

$$tan\theta = \frac{\sum_{i=1}^{n}(x_i^{'2} - y_i^{'2}) + \sqrt{(\sum_{i=1}^{n}(x_i^{'2} - y_i^{'2}))^2 + 4(\sum_{i=1}^{n} x_i^{'} y_i^{'})^2}}{2\sum_{i=1}^{n} x_i^{'} y_i^{'}} . \tag{4.14}$$

where $x_i^{'} = x_i - \bar{x}$, $y_i^{'} = y_i - \bar{y}$.

Step 3: Calculate the standard deviation of the major axis σ_x and the standard deviation of the minor axis σ_y respectively to reflect the dispersion of the data along the primary and secondary directions.

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} w_i (x_i^{'} cos\theta - y_i^{'} sin\theta)^2}{\sum_{i=1}^{n} w_i}} , \tag{4.15}$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n} w_i (x_i^{'} sin\theta - y_i^{'} cos\theta)^2}{\sum_{i=1}^{n} w_i}} . \tag{4.16}$$

Using the spatial statistics toolbox in ArcGIS 10.8, with the rural talent revitalization index from 2008 to 2022 as the weight field, standard deviation ellipse

(SDE) models were generated annually. Key parameters of the SDE for each year are presented in Table 4.4.

The evolution of SDE parameters reveals significant spatial restructuring characteristics of rural talent revitalization in China. The continuous eastward shift of the distribution centroid indicates the concentration of development momentum in the eastern coastal regions. The counterclockwise deflection of the major axis azimuth reflects the strengthening of the "northeast–southwest" axis and the formation of regional development corridors. Meanwhile, the decreasing ellipticity and shrinking dispersion characterize the spatial convergence trend under multi-polar linkage. The ellipse covers areas from the Bohai Rim urban agglomeration in the north, the Guangdong-Hong Kong-Macao Greater Bay Area in the south, the Chengdu-Chongqing Economic Circle in the west, to the core area of the Yangtze River Delta in the east, accurately mapping the spatial coupling relationship between high-value regions of rural talent revitalization and national-level urban agglomerations. This geographical pattern not only confirms the objective law of talent factors concentrating toward major economic growth poles but also highlights the deep-seated driving effect of regional economic gradient differences on the allocation of rural human capital. Economically developed regions continuously attract high-quality talent through industrial upgrading and innovation spillover, while high-density talent agglomeration in turn reinforces regional competitive advantages, forming a positive feedback loop of "economic level–talent development" synergy.

Table 4.4: Standard deviation ellipse parameters for rural talent revitalization

Year	Centroid	Azimuth Angle α/°	Major Axis/km	Minor Axis/km	Ellipticity e
2008	110.8°E,34.6°N	83.53	1337.78	1111.72	1.20
2009	111.1°E,34.6°N	81.07	1318.92	1110.78	1.19
2010	111.2°E,34.6°N	80.66	1302.59	1113.78	1.17
2011	111.3°E,34.7°N	80.46	1295.31	1106.06	1.17
2012	111.5°E,34.7°N	77.93	1272.34	1105.42	1.15

Year	Centroid	Azimuth Angle α/°	Major Axis/km	Minor Axis/km	Ellipticity e
2013	111.6°E,34.7°N	76.49	1263.05	1101.92	1.15
2014	111.8°E,34.5°N	77.04	1239.51	1100.90	1.13
2015	112.1°E,34.4°N	75.40	1216.50	1096.57	1.11
2016	112.2°E,34.3°N	74.21	1204.18	1096.98	1.10
2017	112.4°E,34.3°N	65.77	1152.21	1081.76	1.07
2018	112.6°E,34.2°N	63.26	1171.01	1078.91	1.09
2019	112.6°E,34.3°N	55.99	1180.99	1082.13	1.09
2020	112.8°E,34.5°N	53.87	1162.16	1068.97	1.09
2021	112.7°E,34.3°N	51.21	1176.59	1061.48	1.11
2022	112.7°E,34.3°N	59.54	1178.34	1064.80	1.11

From the perspective of the centre of gravity migration trajectory, the centre of gravity of rural talent revitalization in China has moved from the Henan-Shaanxi junction (110.8°E, 34.6°N) in 2008 to the southeast to the Henan-Hubei-Anhui intersection area (112.7°E, 34.3°N) in 2022, with a cumulative displacement of 172.7 km in 14 years, an average annual moving speed of 11.51 km/year, and a 57.7° angle between the trajectory and the Hu Huanyong line, indicating that the level of talent revitalization is gradually tilting towards the eastern coast. From 2008 to 2018, the Yangtze River Delta and the Pearl River Delta were driven by rapid development, and the centre of gravity shifted east-south at an average annual rate of 13.2 kilometers. From 2018 to 2020, it shifted to the north-eastward direction (8.7 km per year). After 2020, due to the impact of the epidemic and the new urbanization policy, the centre of gravity suddenly shifted to the south-west (an average of 16.4 kilometers per year), and the central and western regions realized the localization of talents through programs such as "New Farmer Cultivation" and "Rural Craftsmen". The Z-shaped trajectory of "southeast - north - southwest" not only reflects the spatial pull of regional strategies but also highlights the short-term adjustment effect of unexpected events on rural talents, marking that the distribution of rural talent revitalization is evolving from the traditional "east-west fragmentation" to a "north-south interaction" pattern.

From the azimuth angle of the standard deviation ellipse, the main spatial direction of rural talent revitalization continues to deviate southward. The azimuth angle α decreasing from 83.53° in 2008 to 59.54° in 2022, indicating that the spatial direction of rural talent revitalization in China shows a northeast-southwest spatial distribution pattern, and the standard deviation ellipse shifts greatly to the south with the passage of time. In 2022, the standard deviation ellipse angle reached the minimum, and the northeast-southwest directional spatial distribution pattern of rural talent revitalization and development in China was strengthened. From the perspective of the changes of the long axis (Y) and the minor axis (X), the standard deviation of the long axis (Y) decreased from 1337.78km in 2008 to 1178.34km in 2013, and the standard deviation of the minor axis increased from 1111.72km in 2008 to 1064.80km in 2022, indicating that the revitalization of rural talents at the provincial level showed a polarization trend and the agglomeration degree of the core area increased. From the perspective of the standard deviation ellipse flattening ratio (the ratio of the long and short axes), the flattening ratio continued to decrease from 2008 to 2022, and the gap between the long and short axes became smaller and smaller, indicating that the spatial directionality of rural talent revitalization in China gradually weakened. The ellipse is getting closer to the circle, and the spatial difference of rural talent revitalization is shrinking.

4.3.2. Spatiotemporal Transfer Evolutionary Analysis

As a classical model to describe discrete spatiotemporal processes, the Markov chain has unique advantages in analyzing the state transition law of complex systems. The core theoretical assumption is that the state of the system at time t only depends on the state characteristics of time $(t+1)$, and has nothing to do with the previous historical state, and this "no memory" property allows the model to effectively strip away the interference of long-term historical paths and focus on the state transition mechanism of adjacent time periods (Alyousifi et al., 2020). In this study, it is necessary to first divide the provinces of China into k discrete grade types (such as low level, medium low level, medium high level and high level) according to the comprehensive evaluation index of development level, and use the quantile method to construct the state space. On this basis, the probability of a province in the defined period T in the i class will be transferred to the j level in the $t+1$ period:

$$P_{ij} = \frac{\sum_{t=1}^{T-1} n_{ij}^{t,t+1}}{\sum_{t=1}^{T-1} n_i^t} \ (i,j = 1,2,...,k) \ . \tag{4.17}$$

In equation (4.17), i and j are indices for the development level classes. Specifically, i denotes the initial class in year t, and j denotes the destination class in year $t+1$. $n_{ij}^{t,t+1}$ represents the number of provinces that transition from level i in year t to level j in year $t+1$ during the research period T, and n_i^t is the total number of provinces at level i in year t. This formula constructs a k×k dimensional transition probability matrix by counting the frequency of state transitions over the years. Its diagonal element P_{ii} reflects the self - maintenance strength of each level, and the off - diagonal element $P_{ij|l}$ reveals the penetration and transition trends between adjacent levels. However, the traditional Markov chain may ignore the spatial constraint of geographical proximity on state transition. To this end, the spatial Markov chain can be introduced. The level states of neighboring provinces are taken as conditional variables to construct a spatial lag - type transition probability matrix $P_{ij|l}$, where l represents the dominant level type of the neighborhood. For example, when the neighborhood is at a high level (l = 4), the conditional probability of the local area transitioning from level i to level j can be expressed as:

$$P_{ij|4} = \frac{\sum_{t=1}^{T-1} n_{ij|4}^{t,t+1}}{\sum_{t=1}^{T-1} n_{i|4}^{t}} \ (i, j = 1,2, \ldots, k) \ . \tag{4.18}$$

This method can not only identify the spatial dependence of regional development, but also quantify the direction and intensity of neighbourhood spillover effects. Through the comparative analysis of the traditional and spatial Markov transfer matrices in STATA 17, the spatiotemporal evolution characteristics of rural talent revitalization and its spatial interaction mechanism can be systematically revealed, as shown in Table 4.5.

Table 4.5: Markov transfer probability matrix of rural talent revitalization from 2008 to 2022

Model	Lag Type	t/(t+1)	I	II	III	IV	Number of observations
Traditional	No Lag	I	0.7931	0.2069	0.0000	0.0000	116
		II	0.0000	0.7521	0.2479	0.0000	117
		III	0.0000	0.0000	0.7522	0.2478	113
		IV	0.0000	0.0000	0.0000	1.0000	88
Spatial	I	I	0.9146	0.0854	0.0000	0.0000	82
		II	0.0000	0.8889	0.1111	0.0000	18
		III	0.0000	0.0000	1.0000	0.0000	1
		IV	0.0000	0.0000	0.0000	0.0000	0
	II	I	0.5000	0.5000	0.0000	0.0000	32
		II	0.0000	0.8028	0.1972	0.0000	71
		III	0.0000	0.0000	0.9167	0.0833	24
		IV	0.0000	0.0000	0.0000	1.0000	1
	III	I	0.5000	0.5000	0.0000	0.0000	2
		II	0.0000	0.5385	0.4615	0.0000	26
		III	0.0000	0.0000	0.7465	0.2535	71
		IV	0.0000	0.0000	0.0000	1.0000	22
	IV	I	0.0000	0.0000	0.0000	0.0000	0
		II	0.0000	0.5000	0.5000	0.0000	2
		III	0.0000	0.0000	0.5294	0.4706	17
		IV	0.0000	0.0000	0.0000	1.0000	65

Results from the traditional Markov model show that each development state exhibits significant path - dependence characteristics. The self - maintenance probabilities of provinces at the low - level (Type I), medium - low - level (Type II), medium - high - level (Type III), and high - level (Type IV) are as high as 79.31%, 75.21%, 75.22%, and 100% respectively. Among them, the complete locking - in effect (with a transition probability of 1.0) for high - level provinces indicates that the "elite club" phenomenon has become the core contradiction in rural talent revitalization. Although there is a 24.79% possibility of upward transition for medium - low - level provinces, the room for progress for low - level provinces is significantly restricted (the probability of I→II is only 20.69%). Moreover, 7% of the provinces in the observation sample have long been trapped in the low - level trap, highlighting the stubbornness of the "poverty depression".

The spatial Markov model further reveals the deep shaping effect of geographical neighborhood on talent revitalization. It shows that the detrimental influence of a low-level neighborhood critically shapes local trajectories. For a province initially at a low level, being surrounded by similar low-level neighbors causes its probability of remaining trapped to jump sharply from 79.31% (in the traditional model) to 91.46%. This powerful negative spatial spillover effect intensifies the “Matthew Effect”, making it significantly harder for disadvantaged areas to achieve upward mobility and locking them into a cycle of “the poor get poorer”. On the other hand, in the high-level neighborhood (Class IV) environment, the probability of transition from medium-to-high-level provinces (Class III) to high level jumped from 24.78% to 47.06%, which confirmed the radiation-driving capacity of developed areas. It is worth noting that the upward traction effect of the medium-level neighborhood (category III) on the medium-level provinces (category II) is particularly prominent, and its 46.15% jump probability is 1.86 times that of the traditional model, implying that the "middle-gradient" provinces assume the strategic function of "transition hub" in the coordinated development of regions. However, the asymmetry of spatial spillover leads to new contradictions: although high-level neighborhoods can significantly increase the upgrade probability of medium- and high-level provinces, they lead to the complete marginalization of low-level provinces in the spatial coordination network (Class I counties completely disappear in Class IV neighborhoods). At the same time, the intensity of the downward penetration effect (such as reverse flow in high → medium) is only one-third of the upward pull effect, and this one-way transmission mechanism may exacerbate the polarization of regional development.

The data reveal two evolutionary characteristics: first, the "double-edged sword" effect of spatial synergy, in which the polarization development of high-level regions not only generates technological spillover dividends, but also exacerbates the brain drain of neighboring underdeveloped regions through factor siphoning, which is reflected in the extremely scarce observations of II→III transfer pathways in the IV neighborhood environment. Second, there is a "vulnerability asymmetry" in the sensitivity of low- and medium-level regions to neighborhood status, that is, the damage intensity of negative spatial shocks (e.g., falling into low-level neighborhoods) on their development trajectories far exceeds the gain effect brought by positive shocks of the same degree (e.g., contact with medium- and high-level neighborhoods), which suggests that there is a spatial game pattern of the "Matthew effect" and "siphon effect" in the process of rural talent revitalization.

4.4. Chapter Summary

Based on the multi-dimensional spatial analysis method, this chapter systematically reveals the spatiotemporal differentiation characteristics and dynamic evolution law of rural talent revitalization in China.

Through the Dagum Gini coefficient decomposition, it was found that the inter-regional difference was the dominant source of the overall difference, and its contribution rate continued to climb over time from 56.86% to 80.95%, and it was found that the overall Gini coefficient decreased from 0.1399 in 2008 to 0.1271 in 2022. In terms of sub-regions, the eastern region had the largest intra-group difference (mean Gini coefficient of 0.1071), and although the intra-group difference decreased from 0.1498 to 0.0933, the agglomeration effect of high-level provinces continued to strengthen. The Gini coefficient in the western region decreased from 0.1077 to 0.0597, indicating that the border provinces were still lagging behind. The equilibrium in the central region was the best (Gini coefficient 0.0428), but the rebound of the difference after 2020 exposed the pressure of transformation. The northeast region fluctuated significantly, with the Gini coefficient dropping from 0.0132 to 0.0052, reflecting the dilemma of low-level equilibrium.

The rightward shift of the national kernel density curve and the trend of multimodality reveal the deep contradiction of "overall improvement, difference solidification, and multipolarization". The main peak in the eastern part shifted from 0.15 to 0.5 to the right, and the tailing divergence showed that the internal gradient expanded, driven by the dual cores of Shanghai, Jiangsu, Zhejiang and Bohai Rim. The single peak in the middle shifted to the right from 0.15 to 0.37, and the peak width narrowed to reflect the synergistic improvement effect of Hubei, Henan and Anhui. The main peak in the western part of the country shifted to the right from 0.1 to 0.34, and the left tail converged after 2017, indicating that policy intervention narrowed the gap between Tibet and Sichuan and Chongqing. The northeast curve shifted the least to the right from 0.15 to 0.35, and the peak symmetry revealed that Liaojihei had fallen into homogenization and low growth.

Spatial correlation analysis showed that the global Moran's I index jumped from 0.3363 to 0.5502, indicating that the spatial dependence of rural talent revitalization was robust. Local Moran's I shows that the Yangtze River Delta and Beijing-Tianjin-Hebei high-value contiguous areas have expanded to 10 provinces, while the southwest cold spot area has spread to the northwest and locked 18 provinces. The centre of gravity of the standard deviation ellipse shifted 172.7 km eastward to form a Z-shaped trajectory, and the azimuth angle shifted 24 degrees southward, revealing the "northeast-southwest" axial strengthening, and the flattening rate decreased by 12.5%, reflecting the complex situation of spatial convergence and polycentric rise.

The spatiotemporal transfer model reveals strong spatial dependence and hierarchical locking, with the self-sustainment probability of high-level provinces reaching 100%, while the lock-in probability of low-level provinces increased by 14.15 percentage points in the backward neighborhood environment. The spatial Markov chain confirms the asymmetry of the neighborhood effect: high-level neighborhoods multiply the probability of upgrading medium- and high-level provinces, but low-level neighborhoods increase the risk of backward regions falling into a "poverty trap" by 1.5 times. The central and western provinces have shown a specific development path, Xinjiang has achieved a breakthrough in talent construction through policy tilt, Qinghai has sprung up in the dimension of talent efficiency but is constrained by the shortcomings of security, and Tibet continues to be at the bottom of the three dimensions (guarantee, construction, efficiency), exposing the systemic development dilemma. This study reveals the spatial game of the "Matthew effect" and "diffusion effect" from the perspective of spatio-temporal coupling, and provides a multi-dimensional empirical basis for differentiated regional policy making.

Chapter 5

Analysis of Factors for the Revitalization of Rural Talents

5.1. Analysis of Obstacle Factors to the Revitalization of Rural Talents

The rural talent revitalization index consists of different dimensions, and different indicator layers contain a number of basic indicators. There are differences in the actual impacts of each dimension and basic indicator on the comprehensive index of rural talent revitalization. In order to further examine the impacts of each dimension and basic indicator on rural talent revitalization, an obstacle degree model is introduced for diagnosis and analysis, so as to identify the key factors restricting rural talent revitalization. The obstacle degree model uses three indicators, namely factor contribution degree, indicator deviation degree, and obstacle degree (Ma et al., 2025) , to analyse and diagnose the indicators. Among them, the factor contribution degree represents the influence of an indicator on the overall objective, the indicator deviation degree reflects the gap between the current status of an indicator and the ideal value, and the obstacle degree represents the constraint intensity of the comprehensive evaluation indicator. The specific calculation process is as follows (Ma et al., 2025):

Step 1: Calculate the factor contribution degree F_{ij} . Suppose the comprehensive evaluation system for rural talent revitalization is composed of m subsystems. The weight of the i-th subsystem is R_i , and it contains n_i basic indicators, with the weight of the j-th indicator being w_j.

$$F_{ij} = R_i \times w_j \; (i = 1,2,\ldots m; j = 1,2,\ldots,n_i)\,. \tag{5.1}$$

In Eq. (5.1), w_j is the weight of the j-th evaluation indicator for rural talent revitalization determined by the entropy weight method.

Step 2: Calculate the deviation of the indicator D_{ij}.

$$D_{ij}^{+} = 1 - X_{ij}^{std}, \tag{5.2}$$

$$D_{ij}^{-} = X_{ij}^{std}. \tag{5.3}$$

In Eq. (5.2) and (5.3), X_{ij}^{std} is the value of the original index after range normalization. Equation (5.2) and (5.3) calculate the deviation degree D_{ij} for each indicator, which quantifies its shortfall from the optimal target. Specifically, Eq(5.2) is used for positive indicators (where a larger value is better), measuring how far the normalized value X_{ij}^{std} falls below 1. Eq. (5.3) is used for negative indicators (where a smaller value is better), treating the normalized value X_{ij}^{std} itself as the degree of deviation.

Step 3: Calculate the obstacle degree of the single indicator.

$$H_{ij} = \frac{F_{ij} \times D_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{n_i} (F_{ij} \times D_{ij})}\,. \tag{5.4}$$

Step 4: On the basis of analyzing the restriction degree of single-direction basic indicators on rural talent revitalization, integrate and measure the obstacle degree of each level to rural talent revitalization.

$$S_i = \sum_{j=1}^{n_i} H_{ij} \; (i = 1,2,\ldots,m)\,. \tag{5.5}$$

5.1.1. Analysis of Obstacles to the Revitalization of Rural Talents in China

Through STATA 17, the obstacle degree of each specific indicator of rural talent revitalization in China was calculated, and the five specific indicators with the largest obstacle degree were selected as the main obstacle factors for rural talent revitalization in China, as shown in Table 5.1. From 2008 to 2022, the following four indicators - rural secondary and tertiary industry talent scale (B1.2), per capita invention patent applications (C1.1), e-commerce platform scale (A3.2), and rural Internet penetration rate (A1.1) - consistently ranked within the top five, making them persistent and crucial factors hindering the advancement of rural talent revitalization nationwide. The fifth position varied across years, with rural governance talent scale (B1.4), agricultural production and management talent scale (B1.1), and proportion of rural residents with junior college education or above (B2.1) also appearing among the top obstacles during different periods. The obstacle degree of the talent scale (B1.2) indicator of rural secondary and tertiary industries has always ranked first.

Table 5.1: Main obstacle factors and obstacle degree of rural talent revitalization in China from 2008 to 2022 (%)

Year	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
2008	B1.2(13.14)	A3.2(12.07)	C1.1(10.79)	A1.1(6.38)	B1.4(6.06)
2009	B1.2(13.33)	A3.2(12.78)	C1.1(10.84)	A1.1(6.66)	B1.4(6.11)
2010	B1.2(13.30)	A3.2(12.63)	C1.1(10.88)	A1.1(6.93)	B1.4(6.06)
2011	B1.2(13.57)	A3.2(11.97)	C1.1(10.94)	A1.1(7.32)	B1.4(5.83)
2012	B1.2(13.62)	A3.2(11.70)	C1.1(10.70)	A1.1(7.61)	B1.1(5.98)
2013	B1.2(13.96)	A3.2(11.46)	C1.1(10.89)	A1.1(7.29)	B1.4(5.96)
2014	B1.2(13.86)	A3.2(11.45)	C1.1(10.70)	A1.1(7.40)	B1.4(5.87)
2015	B1.2(13.96)	A3.2(11.02)	C1.1(10.61)	A1.1(7.45)	B1.4(5.95)
2016	B1.2(13.91)	A3.2(10.93)	C1.1(10.42)	A1.1(7.13)	B1.1(5.93)
2017	B1.2(14.13)	C1.1(10.54)	A3.2(10.31)	A1.1(6.88)	B1.1(5.82)
2018	B1.2(14.22)	C1.1(10.57)	A3.2(10.18)	A1.1(6.69)	B1.4(5.84)
2019	B1.2(14.27)	C1.1(10.83)	A3.2(9.95)	A1.1(6.78)	B1.4(5.85)
2020	B1.2(14.72)	C1.1(11.01)	A3.2(9.08)	A1.1(6.72)	B2.1(5.85)
2021	B1.2(14.81)	C1.1(10.93)	A3.2(8.73)	A1.1(7.12)	B1.4(5.83)
2022	B1.2(15.02)	C1.1(11.00)	A3.2(8.65)	A1.1(6.03)	B2.1(5.72)

Analysis of the main obstacle factors affecting rural talent revitalization in China from 2008 to 2022 reveals persistent and complex structural challenges, which can be examined through the following four dimensions:

Firstly, industrial structural bottlenecks remain prominent. The rural secondary and tertiary industry talent scale (B1.2) indicates a continued weak capacity of non-agricultural sectors to attract and retain talent. This issue is closely linked to the high obstacle levels of infrastructure-related indicators, such as e-commerce platform scale (A3.2) and rural Internet penetration rate (A1.1), reflecting the lag in digital transformation and the development of new business models in rural areas. This not only restricts the distribution channels for agricultural products but also limits employment opportunities in emerging fields like live-streaming e-commerce and digital logistics management for a new generation of skilled farmers.

Secondly, the innovation ecosystem is notably weak. The persistently high obstacle degree of invention patent applications per capita (C1.1), contrasted with the absence of the scientific and technological talent pool (B1.5) from the top five obstacles, reveals that the current rural talent structure remains skewed toward traditional skills. There is a lack of core drivers for technological innovation and application, pointing to a disconnect between the innovation chain and the talent pipeline.

Thirdly, a disconnect exists in policy effectiveness. The consistently high obstacle degree of the rural governance talent scale (B1.4) stands in contrast to policy support indicators, such as government support for agriculture (A2.1) and security guarantees (A2.2), not ranking among the top five obstacles. This suggests that policy inputs have not been effectively translated into grassroots governance efficacy, and institutional barriers preventing talent from being attracted, retained, and well-utilized persist.

Finally, a distinct disconnect has emerged in talent cultivation. The rising obstacle degree of the proportion of rural residents with college education or above (B2.1) in later years underscores a severe drain of higher-educated talent. While the average years of education (B2.2) does not register as a dominant obstacle, this contrast reveals that rural human capital accumulation is trapped in a "low-level equilibrium" where basic educational attainment fails to translate into the retention of advanced skills and knowledge.

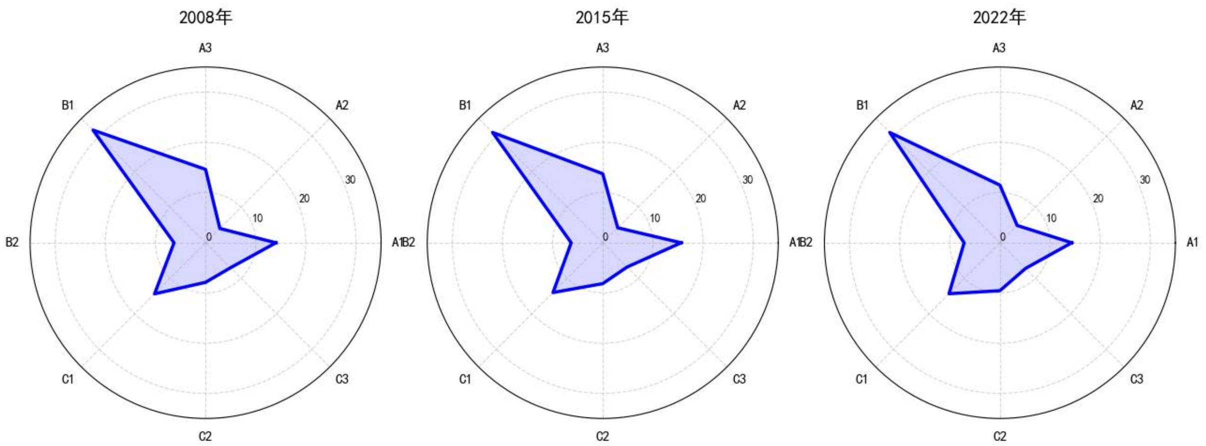

Figure 5.1: Obstacle degree of the indicator layer for rural talent Revitalization (%) for 2008, 2015 and 2022

As shown in Figure 5.1, in terms of the indicator layer, the talent scale structure (B1) has always been the biggest constraint, and its obstacle degree continues to occupy about 30% of the weight, and reaches 31.06% in 2022, reflecting the core contradiction of insufficient matching between the total number of rural talents and the industrial structure. The obstacle to production efficiency (C2) climbed from 7.88% in 2008 to 9.55% in 2022, with an average annual growth rate of 1.2%, becoming the fastest rising indicator, exposing the dual bottlenecks of technology application and large-scale operation in improving agricultural production efficiency. Infrastructure (A1) showed the characteristics of "construction first and then lag", reaching a peak of 15.64% in 2015 and then falling back to 14.32%, suggesting that the marginal benefit of hardware investment is decreasing, and it needs to be turned to improve operational efficiency. The obstacle degree of cultivation platform (A3) has decreased for 14 consecutive years, from 14.61% to 11.48%, but it is still the third major obstacle, indicating that the construction of talent training carriers still needs to be strengthened. It is worth noting that although the quality level (B2) has slowly increased to 7.13%, the huge gap with the scale and structure barriers reveals the structural risk that "the expansion of the number of talents" and the "upgrading of quality" are not synchronized.

5.1.2. Analysis of Obstacle Factors to the Revitalization of Rural Talents in the Regions

Through STATA 17, the obstacle degree of each specific indicator of rural talent revitalization in each region was calculated, and the five specific indicators with the largest obstacle degree in each region were selected as the main obstacle factors for rural talent revitalization in each region, as shown in Tables 5.2, 5.3, 5.4, and 5.5.

Table 5.2: Main Obstacle Factors and Degree of Obstacles to the Revitalization of rural talents in northeast China (%)

Year	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
2008	B1.2(13.55)	A3.2(13.01)	C1.1(10.88)	A1.3(6.36)	B1.4(6.33)
2009	B1.2(14.01)	A3.2(13.45)	C1.1(11.18)	A1.1(6.53)	B1.4(6.08)
2010	B1.2(14.13)	A3.2(13.48)	C1.1(11.43)	A1.1(6.68)	A1.3(6.07)
2011	B1.2(14.06)	A3.2(13.48)	C1.1(11.19)	A1.1(7.11)	A1.3(6.25)
2012	B1.2(14.11)	A3.2(13.56)	C1.1(11.11)	A1.1(7.28)	B1.4(6.40)
2013	B1.2(14.41)	A3.2(13.70)	C1.1(11.29)	A1.1(7.63)	B1.4(6.43)
2014	B1.2(14.20)	A3.2(13.49)	C1.1(11.18)	A1.1(7.46)	B1.4(6.63)
2015	B1.2(14.44)	A3.2(12.56)	C1.1(11.25)	A1.1(7.79)	B1.4(6.99)
2016	B1.2(14.21)	A3.2(11.84)	C1.1(11.03)	A1.1(7.62)	B1.4(6.84)
2017	B1.2(14.10)	A3.2(11.24)	C1.1(11.19)	A1.1(7.59)	B1.4(6.74)
2018	B1.2(14.04)	C1.1(10.99)	A3.2(10.63)	A1.1(8.29)	B1.4(6.48)
2019	B1.2(14.38)	C1.1(10.72)	A3.2(10.85)	A1.1(8.70)	B1.4(6.40)
2020	B1.2(14.38)	A3.2(10.44)	C1.1(10.72)	A1.1(8.70)	B1.4(6.40)
2021	B1.2(14.38)	C1.1(10.46)	A3.2(10.44)	A1.1(9.10)	B1.4(6.43)
2022	B1.2(14.42)	C1.1(10.30)	A3.2(10.27)	A1.1(8.61)	B2.1(6.44)

From 2008 to 2022, as a microcosm of the transformation of traditional industrial bases, the talent scale of rural secondary and tertiary industries (B1.2) ranked first in the obstacle degree for 15 consecutive years, with its value fluctuating between

13.55% and 14.42%, and the average obstacle degree reaching 14.188%, which was higher than the national average of 13.988%, exposing the continuous hindrance of the "industrial hollowing" of the old industrial base to the ability of rural talents to absorb talents. Different from the national trend, the obstacle degree of the scale of the e-commerce platform (A3.2) was always about 1.5 percentage points higher than that of the whole country before 2018, reflecting the dilemma of "big resources and small platforms" of agricultural product e-commerce in northeast China. In 2022, the proportion of rural residents with a college degree or above (B2.1) suddenly appeared on the list, notably higher than the national average. This coincided with the acceleration of the net outflow of population from northeast China, reflecting the special dilemma of the "double loss" of highly educated talents under the "new northeast phenomenon" and the concentration of departments in other provinces and systems.

Table 5.3: Main obstacle factors and degree of obstacle to the revitalization of rural talents in eastern China (%)

Year	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
2008	B1.2(13.36)	A3.2(11.00)	C1.1(10.56)	A1.3(6.58)	B1.4(6.52)
2009	B1.2(13.35)	A3.2(13.03)	C1.1(10.33)	B1.4(6.62)	A1.3(6.31)
2010	B1.2(13.19)	A3.2(12.39)	C1.1(10.44)	B1.4(6.61)	A1.1(6.19)
2011	B1.2(13.85)	C1.1(10.65)	A3.2(9.63)	A1.1(6.94)	A1.3(6.56)
2012	B1.2(14.02)	C1.1(10.11)	A3.2(9.03)	A1.1(7.53)	B1.4(6.74)
2013	B1.2(14.69)	C1.1(10.40)	A3.2(8.09)	B1.4(6.88)	A1.3(6.69)
2014	B1.2(14.51)	C1.1(10.24)	A3.2(8.29)	B1.4(6.70)	A1.3(6.69)
2015	B1.2(14.52)	C1.1(10.18)	A3.2(8.02)	A1.3(6.88)	B1.4(6.73)
2016	B1.2(14.40)	C1.1(9.54)	A3.2(8.00)	B1.1(7.50)	A1.3(6.91)
2017	B1.2(14.52)	C1.1(9.48)	A3.2(7.59)	B1.1(7.58)	B1.4(7.02)
2018	B1.2(14.52)	C1.1(9.48)	B1.1(7.35)	A3.2(7.28)	B1.4(7.02)
2019	B1.2(15.12)	C1.1(9.90)	A3.2(5.78)	B1.4(6.59)	A1.3(6.44)
2020	B1.2(15.12)	C1.1(9.90)	B1.4(6.59)	C2.1(6.52)	A1.3(6.44)
2021	B1.2(15.37)	C1.1(9.75)	C2.1(6.77)	B1.1(6.70)	B1.4(6.62)
2022	B1.2(15.91)	C1.1(9.88)	B1.1(7.22)	C2.1(7.19)	B1.4(6.55)

From the perspective of the change in the degree of obstacles in the eastern region from 2008 to 2022, the scale of rural secondary and tertiary industry talents (B1.2) has always been the biggest constraint factor. Its degree of obstacle has continuously increased from 13.36% to 15.91%, and the gap with other indicators has continued to widen. It shows that when the digital economy absorbs a large number of young talents to flow to the urban service industry, the rural non-agricultural industry falls into the structural dilemma of "high-end blood loss and low-end surplus". The scale of e-commerce platforms (A3.2) had a high degree of obstacle in the early stage (13.03% in 2009), but it declined rapidly after 2015 and has withdrawn from the top five in 2020, indicating that the shortcomings of infrastructure have gradually eased. The number of invention patent applications per capita (C1.1) has been ranked second for a long time, and the obstacle degree is stable in the range of 9% and 11%, reflecting the slow improvement of innovation ability. It is worth noting that the scale of agricultural production and management talents (B1.1) and the output value of agricultural products per mu (C2.1) have gradually entered the top five in or after 2016, reaching 7.22% and 7.19% respectively in 2022, becoming emerging bottlenecks. The scale of rural governance talents (B1.4) has always hovered in the range of 6%-7%, and the ranking has gradually been replaced by new problems. On the whole, there is a double pressure of "stubborn traditional obstacles and prominent emerging problems".

Table 5.4: Main Obstacle Factors and Degree of Obstacles to the Revitalization of Rural Talents in Western China (%)

Year	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
2008	B1.2(12.79)	A3.2(12.21)	C1.1(10.72)	A1.1(6.96)	B1.1(6.49)
2009	B1.2(12.98)	A3.2(12.35)	C1.1(10.81)	A1.1(7.08)	B1.1(6.18)
2010	B1.2(13.00)	A3.2(12.39)	C1.1(10.79)	A1.1(7.21)	B1.4(5.66)
2011	B1.2(13.25)	A3.2(12.58)	C1.1(10.88)	A1.1(7.43)	B1.1(5.85)
2012	B1.2(13.24)	A3.2(12.65)	C1.1(10.74)	A1.1(7.60)	B1.1(6.29)
2013	B1.2(13.43)	A3.2(12.52)	C1.1(10.89)	A1.1(7.77)	B1.1(5.97)
2014	B1.2(13.39)	A3.2(12.46)	C1.1(10.66)	A1.1(7.82)	B1.1(5.70)
2015	B1.2(13.43)	A3.2(12.44)	C1.1(10.43)	A1.1(7.86)	B1.1(5.53)
2016	B1.2(13.47)	A3.2(12.51)	C1.1(10.56)	A1.1(7.52)	B1.1(5.87)
2017	B1.2(13.71)	A3.2(12.05)	C1.1(10.60)	A1.1(7.29)	B1.1(5.71)
2018	B1.2(13.91)	A3.2(12.13)	C1.1(10.83)	A1.1(7.12)	B1.1(5.45)
2019	B1.2(14.35)	A3.2(11.18)	C1.1(11.27)	A1.1(7.09)	B2.1(5.60)
2020	B1.2(14.34)	C1.1(11.27)	A3.2(10.98)	A1.1(6.92)	B2.1(5.61)
2021	B1.2(14.34)	C1.1(11.22)	A3.2(10.98)	A1.1(7.21)	B2.1(5.61)
2022	B1.2(14.43)	C1.1(11.29)	A3.2(10.92)	A1.1(6.22)	B2.1(5.58)

From the perspective of the changes in the degree of obstacles in the western region from 2008 to 2022, the obstacle pattern of rural talent revitalization shows the characteristics of "continuous traditional bottlenecks and initial structural contradictions". As the primary obstacle, the scale of rural secondary and tertiary industry talent (B1.2) increased slowly from 12.79% in 2008 to 14.43% in 2022, with a relatively moderate but sustainable increase, reflecting the long-term constraints of rural industrial upgrading on talent accumulation.The scale of e-commerce platforms (A3.2) is a key obstacle to long-term stability in the western region. Between 2008 and 2018, this factor ranked second in the obstacle for 11 consecutive years, and its value fluctuated from 12.21% in 2008 to 12.13% in 2018, with a limited decline. Although the ranking has dropped slightly to third after 2019, its obstacle degree (10.92% in 2022) is still markedly higher than the national average. This continues to show that there are obvious shortcomings in the construction of modern circulation systems, especially in key links such as cold chain logistics of agricultural products and e-commerce service outlets.The scale of agricultural production and management talents (B1.1) ranked fifth in the early stage, but from 2019, it was replaced by the proportion of rural residents with a college degree or above (B2.1). This means that over time, the shortage of highly educated talent has become a new problem, while the problem of traditional agricultural talent has eased somewhat, but it still exists. At the same time, the number of invention patent applications per capita (C1.1) is affected by the degree of highly educated talents, and the obstacle degree gradually increases, reflecting the lack of innovation ability and the continuous improvement of local education level and scientific research investment.

Table 5.5: Main obstacle factors and obstacle degree to the revitalization of rural talents in central China (%)

Year	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
2008	B1.2(13.37)	A3.2(12.74)	C1.1(11.19)	A1.1(6.94)	B1.4(6.11)
2009	B1.2(13.69)	A3.2(13.02)	C1.1(11.44)	A1.1(7.27)	B1.4(6.24)
2010	B1.2(13.69)	A3.2(13.05)	C1.1(11.43)	A1.1(7.51)	B1.4(6.25)
2011	B1.2(13.62)	A3.2(13.06)	C1.1(11.31)	A1.1(7.72)	B1.4(6.01)
2012	B1.2(13.66)	A3.2(12.32)	C1.1(11.20)	A1.1(7.90)	B1.4(6.25)
2013	B1.2(13.90)	A3.2(12.47)	C1.1(11.30)	A1.1(7.69)	B1.4(6.46)
2014	B1.2(13.84)	A3.2(12.42)	C1.1(11.12)	A1.1(7.81)	B1.4(6.41)
2015	B1.2(14.12)	C1.1(11.26)	A3.2(11.19)	A1.1(7.78)	B1.4(6.47)
2016	B1.2(14.05)	C1.1(10.96)	A3.2(10.95)	A1.1(7.52)	B1.4(6.31)
2017	B1.2(14.42)	C1.1(11.15)	A3.2(9.77)	A1.1(7.22)	B1.4(6.41)
2018	B1.2(14.56)	C1.1(11.18)	A3.2(9.47)	A1.1(6.95)	B1.4(6.27)
2019	B1.2(15.17)	C1.1(12.13)	A3.2(8.96)	A1.1(7.00)	B1.4(6.31)
2020	B1.2(15.17)	C1.1(12.13)	A3.2(8.15)	A1.1(6.75)	B2.1(6.18)
2021	B1.2(15.29)	C1.1(12.20)	A3.2(7.76)	A1.1(7.35)	B1.4(6.20)
2022	B1.2(13.37)	A3.2(12.74)	C1.1(11.19)	A1.1(6.94)	B1.4(6.11)

From the perspective of the changes in the obstacle degree in the central region from 2008 to 2022, the obstacle pattern of rural talent revitalization presents the dual characteristics of "solidification of core contradictions and significant local improvement". As the main obstacle, the scale of rural secondary and tertiary industry talents (B1.2) increased from 13.37% in 2008 to 15.29% in 2021, and the growth trend is steeper than that in other regions, reflecting the structural imbalance between talent supply and demand in the transformation from traditional agricultural provinces to modern industries. The scale of e-commerce platforms (A3.2) was more difficult in the early years, remaining above 12%, but then gradually declining, falling to 7.76% in 2021. This suggests that the e-commerce infrastructure has improved over time in the central region, but the high level of barriers in the early stage may reflect the lack of logistics and network coverage. The obstacle degree of invention patent applications per capita (C1.1) ranked second or third in all years, with values fluctuating between 11% and 12.20%, indicating that the lack of innovation capacity of rural talents in the central region is a continuing problem. This may be related to the inadequacy of educational resources, investment in scientific research or technology transfer mechanisms, which restricts the innovative development of rural areas. The scale of rural governance talents (B1.4) ranks mostly in the fifth position. It has declined somewhat in the later stages but still exists. This reflects the shortage of grassroots governance talents and insufficient management capacity, which affects the implementation of rural policies and community development. It is worth noting that in 2020, B2.1 (the proportion of rural residents with a college degree or above) entered the top five, with an obstacle degree of about 6.18%, indicating that the problem of brain drain or insufficient training of highly educated talents has begun to emerge. This may be related to the uneven distribution of educational resources in the central region or the outflow of young people, resulting in a lack of high-quality talent to support development in rural areas.

5.1.3. Analysis of Obstacles to the Revitalization of Rural Talents at the Provincial Level

The obstacle degree model was used to calculate the obstacle degree of each specific indicator of rural talent revitalization in each province. Due to the large number of indicators and provinces and the existence of multiple years, this study screened out the indicators with an obstacle degree greater than or equal to 5% in each province, and on this basis, the histogram of the frequency distribution of the obstacle factors of rural talent revitalization at the provincial level in 2008, 2015 and 2022 is shown in Figure 5.2. In this study, the obstacle factors with a large degree of obstacle and a general restriction effect on the revitalization of rural talents in various provinces are examined. At the same time, 2022 is used as an example to show the five specific indicators with the greatest obstacles in each province.

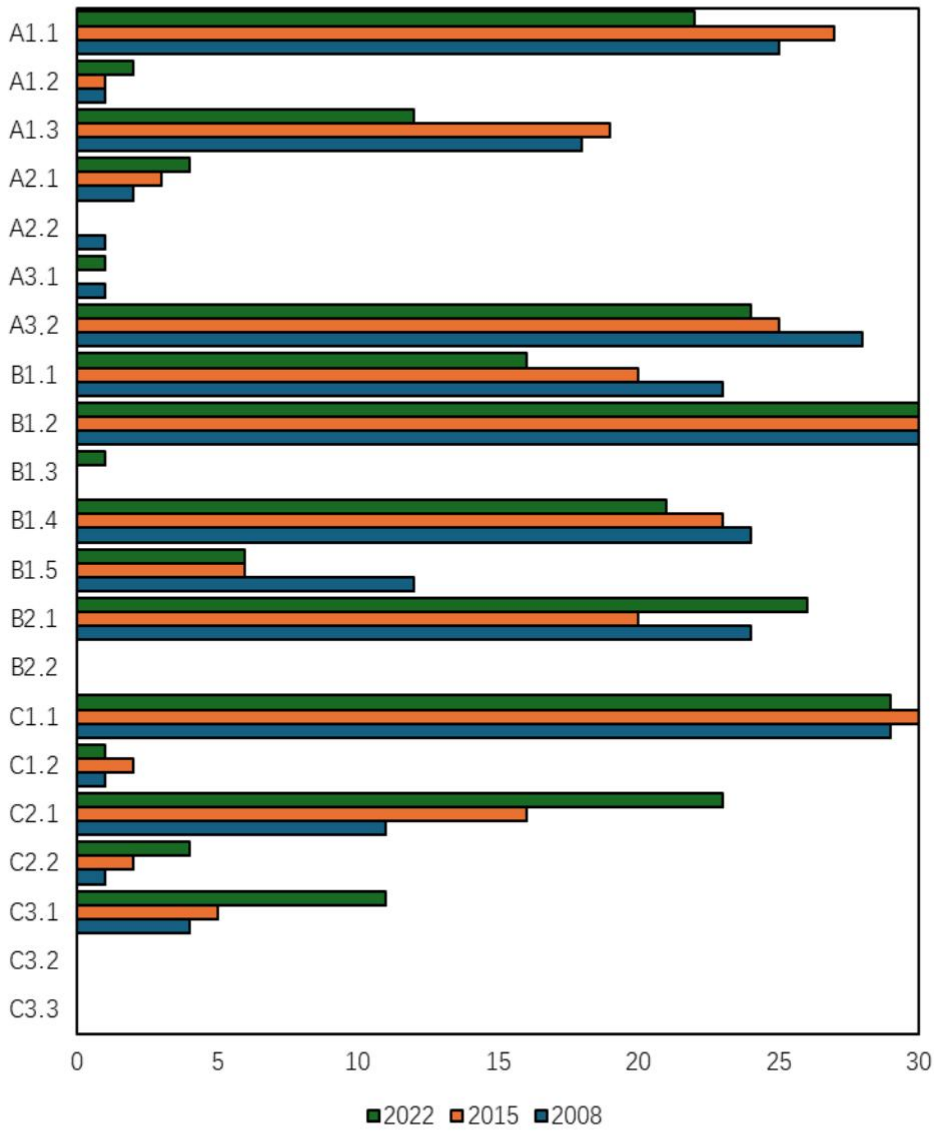

Figure 5.2: Provincial frequency distribution of obstacles to rural talent revitalization

Note: The horizontal axis represents the frequency, which indicates the number of provinces where a specific indicator (e.g., A11, A12) was identified as a major obstacle factor (with an obstacle degree ⩾ 5%) in a given year (2008, 2015, or 2022). The scale from 0 to 30 corresponds to the potential count of provinces.

According to the frequency distribution of obstacle factors for rural talent revitalization in different provinces, it is found that the obstacle factors in 2008, 2015 and 2022 show significant temporal evolution characteristics and structural differences. From the perspective of the overall distribution of obstacle factors, the indicators with a high degree of obstacle degree are mainly concentrated in the fields of technological innovation output, industrial talent scale and rural infrastructure, among which the per capita invention patent application (C1.1) and rural secondary and tertiary industry talent scale (B1.2) have become common obstacles in all provinces in all years, and their frequency of obstacles covers 29-30 and all 30 provinces respectively, indicating that the lack of agricultural science and technology innovation ability and the shortage of rural non-agricultural industry talents are the long-term core constraints of rural talent revitalization. The frequency of obstacles encountered by rural residents with a college degree or above (B2.1) showed a V-shaped trend (2008: 24, 2015: 20, 2022: 26), reflecting the fluctuation in the improvement of rural education levels. This phenomenon is related to the phased changes in the allocation of educational resources and the effectiveness of the policy for talent return. The frequency of obstacles to the scale of e-commerce platforms (A3.2) has gradually decreased from 28 provinces in 2008 to 24 provinces in 2022, indicating that the development of rural e-commerce has achieved certain results in recent years, but the improvement is limited, and there are still restrictions on the development of the e-commerce industry in some areas. The frequency of obstacles to the rural Internet penetration rate (A1.1) fluctuated in the range of 25 to 27, indicating that the construction of digital infrastructure still needs to be strengthened. The frequency of obstacles to the output value of agricultural products per mu (C2.1) continued to rise, from 11 to 23, revealing that the problem of agricultural production efficiency is becoming increasingly prominent. However, the frequency of the (C3.1) obstacle increased from 4 to 11, suggesting that the county-level economy's ability to absorb employment was relatively weak. It is worth noting that some indicators, such as the scale of rural governance talents (B1.4), the scale of agricultural and rural science and technology talents (B1.5), and the coverage rate of rural parks and green spaces (A1.3), show a downward trend, reflecting the positive progress of the optimization of the governance system and the construction of the ecological environment.

Based on the 2022 data on the main obstacle factors for rural talent revitalization across provinces (Table 5.6), the analysis reveals a clear pattern characterized by nationally dominant constraints alongside distinct regional variations. B1.2 (scale of rural secondary and tertiary industry talent) is the primary obstacle in 28 provinces and is particularly prominent in eastern provinces such as Zhejiang (20.78%) and Jiangsu (20.27%), confirming that a shortage of non-agricultural industry talent is the most widespread current bottleneck. C1.1 (invention patents per capita) is similarly a nationwide constraint, ranking among the top five obstacles in 29 provinces, with obstacle degrees ranging from 9.52% to 14.10%. This indicates that weak agricultural science and technology innovation capacity is a common shortcoming across the eastern, central, and western regions. The constraint of B1.4 (rural governance talent scale) is notably high not only in northeastern provinces but also in developed provinces like Jiangsu (11.31%) and Zhejiang (12.42%), reflecting that the modernization of the governance system is an increasingly pressing challenge that intensifies with higher development levels. In contrast, C3.1 (share of migrant workers employed within the county) specifically constrains western provinces such as Gansu (6.11%) and Qinghai (6.07%), revealing insufficient employment absorption capacity in their county-level economies. Megacities like Beijing and Shanghai exhibit a unique obstacle structure, where B1.1 (agricultural production and management talent scale) becomes the primary constraint, directly linked to the shortage of new-type professional farmers for the high-end transformation of urban agriculture. Further comparison shows that in less developed regions like Tibet, the sum of the top three obstacle factors is relatively low (34.66%) and the constraint structure is simpler, whereas in developed regions like Zhejiang, the constraints are more intense and diverse, with the sum of the top three reaching 44.48%. This essentially reflects the contradictory nature of rural talent revitalization at different stages of development, that is, underdeveloped areas mainly deal with basic and single shortages such as talent scale, while developed areas need to deal with systemic and compound bottlenecks composed of multiple factors such as innovation, governance, and industrial upgrading.

Table 5.6: Main obstacle factors and obstacle degree of rural talent revitalization in each province in 2022 (%)

Province	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
Anhui	B1.2(15.19)	C1.1(11.21)	A3.2(7.60)	B1.4(7.26)	B2.1(6.18)
Beijing	B1.1(13.59)	B1.2(10.95)	A1.3(10.52)	C2.1(9.18)	A3.2(8.43)
Fujian	B1.2(19.17)	C1.1(14.10)	C2.1(9.20)	B1.4(7.84)	B2.1(7.02)
Gansu	B1.2(14.65)	A3.2(11.51)	C1.1(10.53)	C3.1(6.11)	C2.2(5.75)
Guangdong	B1.2(17.24)	C1.1(10.38)	B1.1(8.28)	C2.1(7.87)	A1.3(7.01)
Guangxi	B1.2(14.40)	C1.1(11.74)	A3.2(8.41)	B1.4(5.90)	B1.4(3.85)
Guizhou	B1.2(12.86)	C1.1(11.60)	A3.2(10.22)	A1.1(6.98)	B1.1(6.56)
Hainan	B1.2(15.70)	A3.2(12.30)	C1.1(10.98)	A1.3(6.74)	C2.1(6.34)
Hebei	B1.2(16.87)	C1.1(12.95)	B1.4(7.46)	C2.1(7.01)	B2.1(6.94)
Henan	B12(15.59)	C1.1(12.83)	A1.1(7.82)	B2.1(6.76)	B1.4(5.84)
Heilongjiang	B1.2(14.96)	A3.2(11.12)	C1.1(9.83)	B2.1(6.53)	B2.1(6.53)
Hubei	B1.2(15.80)	C1.1(12.75)	A3.2(7.32)	B1.4(5.61)	B2.1(6.37)
Hunan	B1.2(15.57)	C1.1(12.69)	A3.2(9.60)	B1.4(8.35)	A1.1(6.94)
Jilin	B1.2(14.29)	C1.1(11.56)	A3.2(11.28)	A1.1(8.76)	B1.4(6.39)
Jiangsu	B1.2(20.27)	C1.1(11.67)	B1.4(11.31)	B1.1(7.02)	B1.1(7.02)
Jiangxi	B1.2(15.85)	C1.1(12.40)	A3.2(7.10)	C2.1(6.76)	B2.1(6.12)
Liaoning	B1.2(14.01)	C1.1(9.52)	A1.1(8.69)	B1.4(7.43)	B1.4(7.43)
Inner Mongolia	B1.2(15.03)	A3.2(14.51)	C1.1(11.23)	C1.1(11.23)	B2.1(5.89)
Ningxia	B1.2(15.85)	A3.2(13.74)	C1.1(10.11)	C1.1(10.11)	B1.1(6.10)
Qinghai	B1.2(15.73)	A3.2(15.16)	C1.1(11.39)	C3.1(6.07)	B2.1(5.97)
Shandong	B1.2(16.94)	C1.1(12.73)	A1.3(8.46)	B2.1(8.05)	B2.1(8.05)
Shanxi	B1.2(14.53)	C1.1(11.87)	A3.2(9.27)	B1.4(6.06)	B1.4(6.06)
Shaanxi	B1.2(14.64)	C1.1(11.45)	A3.2(7.70)	B1.5(3.25)	B1.4(6.87)
Shanghai	B1.1(14.92)	A1.3(11.58)	A3.2(9.97)	B1.4(5.92)	C2.1(4.05)
Sichuan	B1.2(14.41)	C1.1(11.47)	A3.2(7.79)	A1.3(5.89)	C2.1(5.46)
Tianjin	B1.2(17.36)	A1.1(9.53)	C1.1(8.56)	A1.3(8.00)	A3.2(7.62)
Tibet	B1.2(12.29)	A3.2(11.48)	C1.1(10.89)	C2.1(4.72)	B2.2(2.80)

Province	Obstacle Degree Ranking				
	1st	2nd	3rd	4th	5th
Xinjiang	B1.2(16.45)	C1.1(13.67)	A3.2(12.60)	C2.1(5.77)	B1.4(6.99)
Yunnan	B1.2(13.84)	C1.1(11.16)	A3.2(9.17)	B1.1(6.17)	C2.1(3.95)
Zhejiang	B1.2(20.78)	B1.4(12.42)	C1.1(11.28)	C2.1(8.73)	B1.4(6.04)
Chongqing	B1.2(13.82)	C1.1(10.43)	A3.2(8.89)	C2.1(6.34)	B1.4(6.04)

5.2. Analysis of Influencing Factors for the Revitalization of Rural Talents

Geographically weighted regression (GWR) models study the relationships between different regions by assigning different weights to independent variables at different spatial locations (Brunsdon et al., 1996). However, the traditional GWR model has limitations, it mainly analyses based on cross-sectional data, and ignores the influence of time factors on the model, which makes it insufficient to deal with data with spatiotemporal variation characteristics. In 2010, Huang et al. found that the temporally weighted regression model (TWR) ignored the influence of spatial factors on the model, and in order to solve this problem, the GWR model was expanded and time effects were introduced, thus establishing a geographically and temporally weighted regression model (Geographically and temporally weighted regression, GTWR). The GTWR model is a significant improvement over the GWR model in that it is able to integrate both spatial and temporal information into a weighted matrix, thus effectively capturing the nonstationary characteristics of data under different spatiotemporal conditions (Huang et al., 2010). This improvement allows the GTWR model to more accurately analyse and explain the spatiotemporal variation of geographic phenomena. The steps to use the GTWR model are as follows:

Step 1: Build the GTWR model.

$$Y_i = \beta_0(\mu_i, \nu_i, t_i) + \sum_k \beta_k(\mu_i, \nu_i, t_i)\, X_{ik} + \varepsilon_i \,. \tag{5.6}$$

In Formula (5.6), Y_i represents the observed value of the dependent variable at the i-th sample point. $\beta_0(\mu_i, \nu_i, t_i)$ is the regression constant term of the i-th sample point, that is, the intercept term in the model, and it is related to the longitude μ_i, latitude ν_i, and time t_i of the spatiotemporal coordinates of the sample point. $\Sigma_k \beta_k(\mu_i, \nu_i, t_i) X_{it}$ is the linear combination of the independent variable part, $\beta_k(\mu_i, \nu_i, t_i)$ is the k-th regression parameter of the i-th sample point, and X_{ik} is the value of the k-th independent variable at the i-th sample point. ε_i is the residual term, representing the part that the model fails to explain, and it is usually assumed to follow a normal distribution with a mean value of 0.

Step 2: Estimate the regression parameters in the GTWR model.

$$\widehat{\beta}(\mu_i, \nu_i, t_i) = [X^t W(\mu_i, \nu_i, t_i) X]^{-1} X^t W(\mu_i, \nu_i, t_i) \mathrm{Y} \; . \tag{5.7}$$

In Eq. (5.7), $\widehat{\beta}(\mu_i, v_i, t_i)$ is the estimated value of the regression parameter $\beta_k(\mu_i, \nu_i, t_i)$. X represents the matrix of independent variables, each column represents the observed value of an independent variable at all sample points, and each row corresponds to the value of all independent variables at a sample point. $X^t W(\mu_i, v_i, t_i)$ is the spatiotemporal weight matrix, which is used to measure the spatiotemporal correlation between different sample points.

The spatiotemporal weight matrix is constructed by integrating spatial and temporal proximity. The composite spatiotemporal distance between sample points i and j is calculated as:

$$d_{ij}^{st} = \sqrt{\lambda_s[(u_i - u_j)^2 + (v_i - v_j)^2] + \lambda_t (t_i - t_j)^2} \tag{5.8}$$

Where λ_s and λ_t are scaling parameters balancing spatial and temporal effects. A bi-square kernel function is applied to convert this distance into a weight:

$$\omega_{ij} = \begin{cases} [1 - (d_{ij}^{st}/h)^2]^2, & if \; d_{ij}^{st} < h \\ 0, & otherwise \end{cases} \tag{5.9}$$

Here, h is the bandwidth determining the radius of influence. This method allows nearby points in both space and time to have greater influence on the local regression estimate at point i, thereby enhancing the model's ability to capture local spatiotemporal features.

Step 3: Determine the bandwidth.

The bandwidth h in Eq. (5.9) is a crucial parameter, as it determines the attenuation rate and spatial extent of the weight function, thereby notably influencing the estimation of local parameters. The optimal bandwidth is determined adaptively by minimizing the corrected Akaike Information Criterion (AICc), calculated as:

$$AIC_c = 2nln(\widehat{\sigma}) + nln(2\pi) + \frac{n+tr(S)}{n-2-tr(S)} \tag{5.10}$$

where n is the sample size, $\widehat{\sigma}$ is the estimated standard deviation of the residuals, and $tr(S)$ is the trace of the hat matrix, representing model complexity. This criterion balances goodness-of-fit (the first term) against model complexity (the third term), effectively preventing overfitting or underfitting. The adaptive bandwidth mechanism allows h to vary based on local sample density, granting the model greater flexibility to capture spatiotemporal heterogeneity across different regions and time points.

5.2.1. Selection of Influencing Factors and Data Testing

Based on the theory of regional development and the theory of urban-rural integration development, this study reveals the co-shaping effect of the dynamic interaction between physical geographical factors and rural social and economic factors on the spatiotemporal differentiation characteristics of rural talent revitalization, and focuses on exploring the influencing factors and functional paths of key factors at the level of regional social development on the formation of the spatiotemporal pattern of rural talent revitalization. Drawing on the existing results, the economic driving dimension focuses on the convection of urban and rural factors and the efficiency of capital allocation, selects the urban-rural income gap (disposable income of urban residents/disposable income of rural residents, x1) to reveal the intensity of the "push-pull effect", and uses the per capita fixed asset investment in rural areas (x2) to characterize the capital accumulation level of the rural economy. The social carrying dimension focuses on the spatial reconstruction of population and the stability of human capital, constructs the rural population density (permanent population of administrative villages/area of village construction, x3) to measure the carrying capacity of social services, and uses the proportion of inter-provincial migrant labour (x4) to reflect the pressure of human capital loss. In the dimension of natural constraints, the background of the geographical environment and the ecological carrying threshold are comprehensively considered. The topographic relief (x5), calculated by a surface roughness algorithm based on 90m Digital Elevation Model (DEM) data, is introduced to represent spatial accessibility constraints. The DEM is a digital representation of ground surface topography. The regional ecological environment is evaluated by the unit GDP pollutant emissions (SO_2 emissions/GDP, x6).

In the process of constructing the GTWR model, this study strictly followed the technical specifications of spatial econometric analysis to ensure the scientificity and reliability of the model. In order to solve the problem of the interference of multidimensional variables on parameter estimation caused by dimensional differences, the Gaussian standardization method was used to remove dimension from all explanatory variables. By calculating the Z-score values of each variable, the standardized transformation of data distribution morphology is realized, the influence of different dimensions and dimensional units on the model estimation is eliminated, and the stability and accuracy of the model are improved. To avoid model estimation errors, the study further employed the Variance Inflation Factor (VIF) diagnostic method to conduct a multicollinearity test on the standardized driving factors. The data were processed and analysed using SPSS 27 and the VIF values for all variables were significantly lower than the empirical threshold value of 5. This result not only confirms that there is no significant collinearity between the variables, but also satisfies the basic assumptions of model construction and ensures the validity and reliability of the model estimation, as shown in Table 5.7.

Table 5.7: VIF Verification Results

Indicator	Tolerance	VIF
x1	.5919	1.6895
x2	.8262	1.2104
x3	.7557	1.3233
x4	.6860	1.4577
x5	.4729	2.1144
x6	.7982	1.2528

Table 5.8: Model parameter estimation results

Model	OLS	TWR	GWR	GTWR
AICc	750.42	400.34	459.80	192.78
R^2	0.7202	0.8967	0.8964	0.9537
Δ AICc	0	-350.08	-290.62	-557.64
Δ R^2	0	0.1765	0.1762	0.2335

Note: ΔAICc and ΔR^2 represent the differences relative to the OLS model. Specifically, ΔAICc indicates the reduction in AICc compared to the OLS baseline, and ΔR^2 indicates the improvement in R^2 compared to the OLS baseline.

In order to further validate the spatiotemporal interpretation advantages of the GTWR model, four regression models including Ordinary Least Squares Regression (OLS), TWR, GWR, and GTWR models were constructed using ArcGIS 10.8, and the results are shown in Table 5.8. From the perspective of model fit, the adjusted R^2 of the GTWR model reached 0.9537, which was 6.39%, 6.36% and 32.42% higher than that of the GWR model (0.8964), TWR model (0.8967) and OLS model (0.7202), respectively. These results show that the inclusion of spatiotemporal dual nonstationary features significantly enhances the fit of the model. Specifically, the GTWR model can more accurately capture the spatiotemporal dynamic changes of various influencing factors in the process of rural talent revitalization by considering the nonstationarity of both geospatial and temporal dimensions, thereby improving the goodness of fit of the model to the data. From the perspective of the information criterion, the AICc of the GTWR model is 192.78, which is 266.02, 207.56 and 557.64

units lower than that of the GWR model (459.80), TWR model (400.34) and OLS model (750.42), respectively. This result further confirms the validity of the parameter estimation of spatiotemporal heterogeneity. A lower AICc value indicates a better prediction performance of the model while avoiding overfitting. The minimized AICc signifies that the GTWR model can more effectively balance the relationship between model complexity and goodness of fit when processing the spatiotemporal data of rural talent revitalization. The empirical results show that the GTWR model effectively solves the problem of "double ignorance" of the spatiotemporal dynamic features of the traditional spatial econometric model by embedding the geographic coordinate matrix and the temporal decay function at the same time. Specifically, the geographic coordinate matrix enables the model to capture the spatial heterogeneity between different regions, while the time decay function can reflect the dynamic effects of each influencing factor over time. This dual mechanism makes the GTWR model have better quantitative ability in analyzing the spatiotemporal evolution mechanism of rural talent revitalization, and provides a more reliable analytical tool for in-depth understanding of the influencing factors and spatiotemporal variation of rural talent revitalization. In conclusion, the GTWR model has significant advantages in explaining the spatio-temporal dynamic characteristics of rural talent revitalization, and provides a scientific and effective analytical method for related research.

5.2.2. Temporal and Spatial Evolution Characteristics of the Influence of Driving Factors

Based on the GTWR model, this study measured the spatiotemporal dynamic correlation between the level of rural talent revitalization and the influencing factors in 31 provinces of China from 2008 to 2022, and the results showed that there was significant spatiotemporal heterogeneity in the intensity and direction of the action of each factor, and then a box plot of each coefficient with time was drawn to observe its temporal evolution trend, as shown in Fig. 5.3.

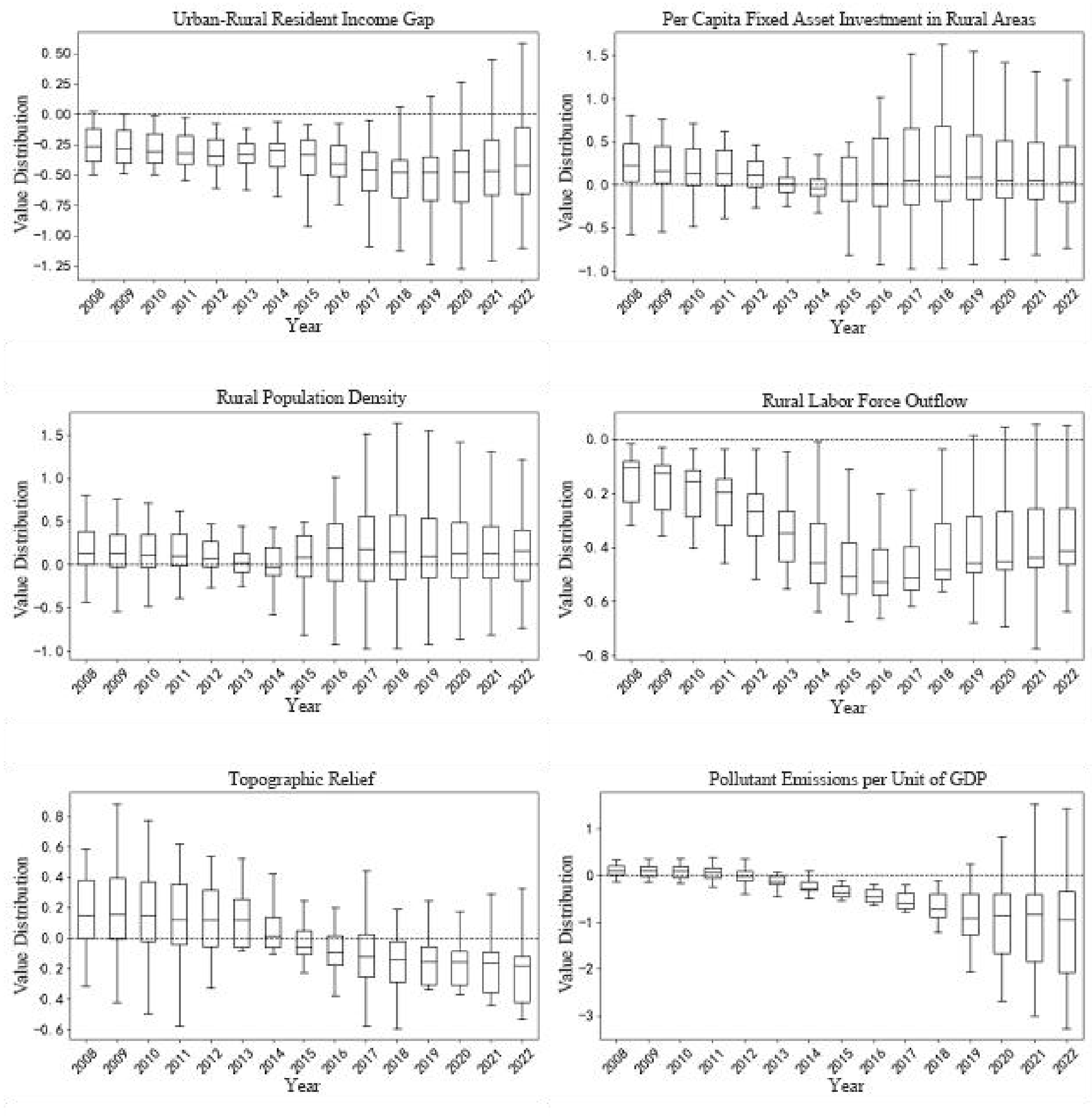

Figure 5.3: Trend of regression coefficients in the GTWR model from 2008 to 2022

Note: Box plots illustrate the annual variations in local regression coefficients estimated by the GTWR model, quantifying the time-varying influence strength and direction (positive/negative) of each factor

During the research period from 2008 to 2022, the impact of the income gap between urban and rural residents (x1) on rural talent revitalization was generally negative. The regression coefficient changed from -0.2607 to -0.3894, indicating that the expansion of the income gap between urban and rural areas had a continuous hindering effect on rural talent revitalization. This negative impact fluctuated among different provinces and the differences gradually widened, which may be related to various factors such as the economic development level of different regions, the implementation effect of policies, and the adjustment of the rural industrial structure.

The impact of per capita fixed asset investment in rural areas (x2) on the revitalization of rural talents showed a certain volatility during the study period. The regression coefficient decreased from 0.2117 to 0.1273, showing a downward trend and a negative value in 2013, indicating that its role in promoting the revitalization of rural talents is weakening. This may be related to factors such as investment efficiency, capital allocation, and investment direction, and some regions may not be able to effectively translate fixed asset investment into a condition for attracting and retaining talent.

The impact of rural population density (x3) on rural talent revitalization is similar to that of per capita fixed asset investment, showing a certain degree of volatility. The regression coefficient fluctuates between 0.0351 and 0.3653, and remains positive on the whole, indicating that rural population density has a certain role in promoting the revitalization of rural talents, but this effect varies in different years and regions, and may be affected by factors such as rural population flow, urbanization process and rural economic development. The impact of rural labor force outflow (x4) on rural talent revitalization shows strong volatility and a clear negative trend, and the box plot in the chart is widely distributed and changes dramatically over time. The regression coefficient changed from -0.1855 to -0.2811, and the negative value continued and increased in intensity, indicating that the continuous loss of rural labour force posed a great obstacle to the revitalization of rural talents, which may affect the sustainable development of rural economy and the stability of rural society. The negative value of topographic relief (x5) on the revitalization of rural talents has been increasing in recent years, and the regression coefficient has decreased from 0.1989 to -0.4212, indicating that the topographic relief of some provinces has changed from a positive promoting effect to a negative inhibitory effect on the revitalization of rural talents. This may be related to the impact of topographical conditions on the construction of infrastructure such as transportation and communications, which in turn affects the flow of talent and the allocation of resources.

The impact of pollutant emissions per unit of GDP (x6) on the revitalization of rural talents was negative, and the regression coefficient decreased from 0.1142 to -1.0454, and the negative value gradually increased, indicating that environmental pollution has an increasingly negative impact on the revitalization of rural talents. The box plot shows that inter-provincial variation increased markedly in the later years (approximately post-2016). While provincial values were relatively clustered in the earlier period, the interquartile range expanded and the number of outliers grew substantially later on. This means that the strengthof the negative impact not only increased overall but also became much more varied across different provinces. Therefore, the intensifying negative coefficient reflects two concurrent dynamics: on the one hand, a strengthening of the average nationwide inhibitory effect of pollution on talent revitalization, which likely degrades rural habitability and deters talent. On the other hand, a widening disparity in how severely different provinces experience this constraint. This heterogeneity suggests that regions are diverging in their environmental performance or in their vulnerability to pollution's socio-economic effects, making a uniform national policy response insufficient. Targeted interventions are needed, especially for provinces that appear as persistent negative outliers in the later years of the data.

According to the mean regression coefficient data of each province from 2008 to 2022 based on the Geographic Spatiotemporal Weighted Regression (GTWR) model, the influencing mechanism of rural talent revitalization in China shows considerable spatial heterogeneity and regional differentiation, as shown in Table 5.9.

Table 5.9: Mean regression coefficients of each province in the GTWR model from 2008 to 2022

Province	X1	X2	X3	X4	X5	X6
Anhui	-7.2566	3.0980	1.7175	-5.1726	-0.3785	-6.7119
Beijing	-6.6791	3.1367	1.3551	-5.6351	0.2595	-9.4445
Fujian	-6.8309	0.9314	2.8040	-3.8166	-0.1792	-3.1347
Gansu	-16.8560	0.8578	2.9423	4.8640	-14.0055	-3.6212
Guangdong	-4.2135	0.5174	3.3773	-6.2630	-0.6050	-4.0000
Guangxi	-4.9078	-1.5997	4.9794	-6.8614	-1.8648	-2.8478
Guizhou	-7.4393	-0.0525	1.3454	-5.1605	4.1856	-9.8789
Hainan	-1.8322	4.6868	3.0607	-6.2745	0.0072	-12.5445
Hebei	-13.2333	-1.7139	-0.4829	-5.3825	10.0602	-4.8020
Henan	-9.6777	1.2554	0.7378	-5.3374	2.9886	-5.2971
Heilongjiang	-7.2490	-4.4985	10.8854	0.1927	2.3556	6.3640
Hubei	-1.5512	3.6838	5.6834	-11.8239	-4.0931	-15.9140
Hunan	-3.2969	9.0190	4.1253	-6.7482	-1.3587	-7.4985
Jilin	-4.1806	0.3238	5.0425	-2.0868	-1.6287	-1.3317
Jiangsu	-4.8611	6.2697	2.6646	-5.8916	-1.6513	-8.4293
Jiangxi	-5.3200	7.5972	7.0825	-13.3853	-10.2876	-13.6508
Liaoning	-5.6406	-0.9972	8.2011	-0.8550	-0.6990	4.4933
Inner Mongolia	-7.9955	-4.3880	5.2592	-1.8300	5.3091	1.6125
Ningxia	-9.1387	0.5614	0.5428	-5.5738	4.2727	-8.4544
Qinghai	-4.0688	0.0240	3.1157	-2.3184	-1.2884	1.0612
Shandong	-6.2350	2.3270	1.4139	-5.5744	1.1573	-10.2364
Shanxi	-4.4398	-1.6830	4.4237	-6.3567	-1.2061	-2.4113
Shaanxi	-7.7798	0.3095	0.2230	-2.0740	1.7856	1.1326
Shanghai	-2.8287	7.3496	3.4943	-6.3538	-0.7140	-9.7078
Sichuan	-5.2429	1.0280	3.4906	-5.4056	-1.1320	-4.6156
Tianjin	-1.0137	5.3811	4.0962	-7.1495	1.7762	-12.4862
Tibet	-0.8481	4.4970	3.8381	-7.0337	1.6092	-13.2053
Xinjiang	-3.9981	-0.1417	4.2611	-3.3168	-1.7217	-3.5925
Yunnan	-3.8315	-1.4057	4.1129	-4.6179	-1.2462	-3.0819
Zhejiang	-7.3698	8.0918	8.1882	-13.2340	-11.4089	-10.6692
Chongqing	-4.3454	8.1077	3.5244	-6.3120	-1.3466	-7.5948

The mean regression coefficients from 2008 to 2022 (Table 5.9) reveal pronounced spatial heterogeneity in the impact of the urban-rural income gap (x1) on rural talent revitalization across Chinese provinces. While the coefficient is negative nationwide, indicating a generally inhibitory effect, its magnitude varies dramatically. For instance, in Gansu Province, the coefficient is as low as -16.8560, suggesting the income gap poses a severe constraint, likely intertwined with the region's lagging economic development and a less diversified rural industrial structure. In contrast, economically developed municipalities like Beijing (-6.6791) and Shanghai (-2.8287) exhibit relatively weaker negative impacts. This disparity may be attributed to their superior infrastructure, richer educational resources, and greater availability of off-farm employment opportunities, which can partially mitigate the adverse effects of income disparity on talent retention and attraction.

There are considerable differences in the impact of per capita fixed asset investment (x2) on the revitalization of rural talents in different provinces. Some provinces, such as Hunan, Jiangsu, and Zhejiang, have a high mean coefficient of x2, indicating that these regions have played a significant role in promoting the revitalization of rural talents in terms of rural fixed asset investment, which may be due to their strong economic strength and emphasis on rural infrastructure construction. However, some provinces, such as Gansu Province and Guangxi Zhuang Autonomous Region, have low or even negative regression coefficients of x2, indicating that rural fixed asset investment in these areas has not been effectively transformed into a driving force for the revitalization of rural talents, which may be related to factors such as unreasonable investment direction and low investment efficiency.

The impact of rural population density (x3) on the revitalization of rural talents also varies among different provinces. In some provinces, such as Heilongjiang and Liaoning, the regression coefficient of x3 is relatively high, indicating that rural population density has a certain role in promoting the revitalization of rural talents in these areas, which may be related to factors such as the relative concentration of educational resources and more employment opportunities in densely populated areas. However, in some provinces, such as Gansu Province and Qinghai Province, the regression coefficient of x3 is low, indicating that the impact of rural population density on the revitalization of rural talents is weak, which may be related to factors such as slow economic development and serious population outflow in these areas.

Rural labour loss (x4) has an inhibitory effect on the revitalization of rural talents in most provinces, and the regression coefficient is negative. For example, in Anhui Province and Henan Province, the regression coefficients of x4 are -5.1726 and -5.3374, respectively, indicating that the large loss of rural labour in these areas poses a great obstacle to the revitalization of rural talents, which may affect the sustainable development of rural economy and the stability of rural society. In Gansu Province, for example, the regression coefficient of x4 is 4.8640, which is positive, which may be related to the relatively low rural labour loss in the region, or other factors that offset the negative impact of labour loss to some extent.

The impact of terrain undulation (x5) on rural talent revitalization has significant spatial heterogeneity, and the regression coefficient varies drastically, ranging from strong positive to strongly negative. For example, in Guizhou Province and Gansu Province, the regression coefficients of x5 are 4.1856 and -14.0055, respectively, indicating that there are significant differences in the impact of topographic conditions on the revitalization of rural talents in these regions. It may be related to the impact of topographic conditions on the construction of infrastructure such as transportation and communications, which in turn affects the flow of talents and the allocation of resources.

The contribution of pollutant emissions per unit of GDP (x6) to the revitalization of rural talents in most provinces is negative, and the regression coefficient is negative. For example, in Beijing and Shanghai, the regression coefficients of x6 are -9.4445 and -9.7078, respectively, indicating that environmental pollution has a great negative impact on the revitalization of rural talents in these areas, which may affect the quality of life and health of rural residents, and then restrict the attraction and retention of rural talents. For regions such as Heilongjiang Province and Liaoning Province, the regression coefficient of x6 is positive. This might be related to the fact that these areas place relatively greater emphasis on environmental protection during their economic development process, or the impact of their pollutant emissions on rural areas is relatively smaller.

5.2.3. Analysis of the Driving Mechanism

The spatio-temporal differentiation characteristics of rural talent revitalization are essentially the dynamic outcome of multi-dimensional interaction among the natural geographical foundation, social economic factors, and the institutional environment. The internal mechanism of its effect is manifested as the coordinated evolution of a composite system of "geographical constraints - economic drives - social carrying capacity". The urban-rural income gap reconstructs the spatial allocation logic of human capital through the push-pull effect, and the high ratio not only directly accelerates the urban migration of rural elites in search of higher incomes and better development opportunities, but also deeply changes the intergenerational preference of household human capital investment and induces the continuous shrinkage of the rural skill formation system. The hedging is the leverage effect of rural fixed asset investment, which activates the endogenous development momentum of rural areas by improving the accumulation of physical capital, improves the attractiveness of rural areas, and helps to retain and attract talents. However the investment efficiency is affected by the topographic undulation, and in the mountainous areas with high terrain undulation, the traffic damping effect makes the talent adsorption capacity under the same investment intensity lower than that in the plain areas, and this spatial heterogeneity requires capital investment to form adaptability with the geographical background.

As the core indicator of social carrying capacity, rural population density affects the efficiency of public service supply through population size. Low-density areas fall into a negative cycle of "population loss→ idle facilities→ rising service costs", and the knowledge spillover effect generated by moderate agglomeration can give birth to the growth ecology of local talents. Rural labour loss will have a complex non-linear impact, and the talent pool will be formed through capital and technology feedback in the early stage, but when the labour outflow exceeds the critical scale, the centre of gravity of the social network will shift outward, which will lead to a fault crisis in the rural human capital structure. This dynamic evolution is implicitly screened by environmental quality, and high-pollution emission areas not only weaken the willingness to retain local talents, but also inhibit the endogenous cultivation of high-quality labour through the industrial lock-in effect. It is worth noting that the natural geographical elements are not one-way constraints, and the topographic relief can be transformed into the spatial viscosity of characteristic agricultural development under specific circumstances; for example, the coupling of hilly landform and ecological planting can form a "geographical brand effect", thereby attracting the concentration of specialized talents.

The interaction of various elements further shapes the spatial pattern of talent revitalization. The urban-rural income gap and fixed asset investment form a dynamic game of "centrifugal-centripetal" force, and its equilibrium point depends on the corrective effect of topographic conditions on the flow cost of factors. The interaction between population density and migrant migration is dependent on spatial scale, with moderate flow at the micro level promoting knowledge diffusion, while excessive loss at the macro level leads to the dissipation of social capital. Environmental quality reshapes the demand structure of industrial talents through the pressure of green transformation, when pollution emissions exceed a certain threshold, it triggers a transformation of development models, thereby changing the relative weight of economic factors and natural factors. This multidimensional coupling mechanism shows significant imbalance in the spatiotemporal dimension. The economic factors in the plain area dominate the concentration of talents, while the mountainous areas show strong interaction characteristics between natural constraints and social bearing, while the influence of environmental quality in ecologically fragile areas is affected by policy intervention. This mechanism reveals that the revitalization of rural talents is not the result of the linear effect of a single factor, but the emergent characteristics of the possibility space provided by the geographical environment and the active choice of social and economic factors.

5.3. Summary of this Chapter

This chapter analyses the obstacle factors and influencing factors of rural talent revitalization through the obstacle degree model and the geographic time-weighted regression model.

In the analysis of the obstacle factors to the revitalization of rural talents. Specifically:

(1) At the national level, the scale of rural secondary and tertiary industry talents, the per capita number of invention patent applications, the scale of e-commerce platforms, the rural Internet penetration rate, and the scale of rural governance talents are the main obstacles, and these obstacles are relatively stable in different years, reflecting the structural contradictions in the revitalization of rural talents.

(2) At the regional level, the northeastern, eastern, western and central regions each present different obstacle characteristics.

① The scale of rural secondary and tertiary industries in northeast China has ranked first in terms of obstacle level for 15 consecutive years , and its numerical fluctuation range is noticeably higher than the national average, and the obstacle degree of e-commerce platform scale has always been about 1.5 percentage points higher than that of the national level before 2018, and the proportion of rural residents with college degree or above in 2022 is suddenly on the list of obstacles.

② The scale of rural secondary and tertiary industry talents in the eastern region remains the primary constraint, with its obstacle degree increasing annually. Although initially high, the obstacle degree for e-commerce platform scale declined rapidly after 2015. Per capita invention patent applications have long ranked second.

Furthermore, the scale of agricultural production/operation talent and agricultural output value per mu have gradually entered the top five obstacles since 2016, while rural governance talent scale has consistently ranged between 6% and 7%.

③ The obstacle pattern of rural talent revitalization in the western region is characterized by "the traditional bottleneck continues and the structural contradiction is beginning to appear". The obstacle degree of the rural secondary and tertiary industry talent scale is slowly rising, the obstacle degree of e-commerce platform scale is limited and always higher than the national average, and the scale of agricultural production and operation talent ranks fifth in the early stage, but it is replaced by the proportion of rural residents with college degree or above after 2019.

④ The trend of increasing barriers to the development of talent in the secondary and tertiary sectors in rural areas of the central region is steeper compared to other regions. The barriers to the growth of e-commerce platforms were high in the early years but gradually decreased thereafter. The average number of invention patent applications per person ranked third for most years, while the scale of talent in rural governance generally ranked fifth, although it has declined somewhat over time. In 2020 and 2021, the proportion of rural residents with a college degree or higher entered the top five.

(3) At the provincial level, the obstacle factors in 2008, 2015 and 2022 showed significant temporal evolution characteristics and structural differences, and the indicators with higher barriers were mainly concentrated in the fields of technological innovation output, industrial talent scale and rural infrastructure, among which the per capita invention patent application and rural secondary and tertiary industry talent scale became common obstacles in all provinces.

In the analysis of the influencing factors of rural talent revitalization, the mechanism of six factors, including the urban-rural income gap, the per capita investment in fixed assets in rural areas, the rural population density, the proportion of inter-provincial migrant labour, the topographic relief and the pollutant emissions per unit of GDP, was discussed. The results show that the impact of urban-rural income gap on the revitalization of rural talents is negative, and the regression coefficient changes from -0.2607 to -0.3894, indicating that the widening of urban-rural income gap has a continuous hindrance effect on the revitalization of rural talents, and the differences between different provinces are gradually increasing. The impact of per capita investment in fixed assets on the revitalization of rural talents showed a certain volatility during the study period, and the regression coefficient decreased from 0.2117 to 0.1273, showing a downward trend as a whole, and a negative value in 2013, indicating that its role in promoting the revitalization of rural talents is weakening. The impact of rural population density on the revitalization of rural talents is relatively stable, and the regression coefficient fluctuates between 0.0351 and 0.3653, and the overall value remains positive, indicating that rural population density has a certain role in promoting the revitalization of rural talents, but there are differences in different years and regions. The outflow of rural labor had a marked and strengthening inhibitory effect, with its negative coefficient increasing from -0.1855 to -0.2811 over the study period. The negative value of topographic relief on the revitalization of rural talents has been increasing in recent years, and the regression coefficient has decreased from 0.1989 to -0.4212, indicating that the topographic relief of some provinces has changed from a positive promoting effect to a negative inhibitory effect on the revitalization of rural talents. Similarly, the pollutant emissions per unit of GDP shifted from a slightly positive to a strongly negative influence, with the coefficient dropping from 0.1142 to -1.0454, signifying that environmental pollution has become an increasingly detrimental factor over time.

Chapter 6

Conclusions and Suggestions

6.1. Conclusions

From 2008 to 2022, the comprehensive level of rural talent revitalization in China showed a significant improvement trend, with the index value increasing from 0.1357 to 0.3814, an increase of 181%, and the overall evolution experienced a three-stage evolution of "slow climbing, accelerated development, and steady optimization". At the national level, the contribution of talent construction dimension is the highest, and indicators such as the scale of rural secondary and tertiary industries and the scale of e-commerce platforms have become the core driving factors, but structural contradictions such as insufficient adsorption capacity and weak innovation ability of rural non-agricultural industries have existed for a long time. The eastern region maintained its absolute leading position with an average annual growth rate of 7.98%, and the index reached 1.55 times that of the western region in 2022. The central region has achieved overtaking through high-intensity investment in talent construction, but the transformation of efficiency lags behind. The western region narrowed the gap by virtue of the strategy of prioritizing talent efficiency, and the growth rate of talent construction was the greatest, but it was constrained by the weak basic support. The northeast region fell into a low-speed fluctuating growth due to population outflow and sluggish industrial transformation, and the index level was 33.6% lower than that in the east.

At the provincial level, Shanghai, Beijing, and Zhejiang are at the forefront of economic agglomeration and policy innovation, while western provinces such as Tibet and Yunnan continue to be at the bottom due to geographical constraints and lagging infrastructure. In the dynamic evolution, 15 provinces, including Anhui and Fujian, have achieved a leap in ranking through the synergy of the industrial chain and talent chain, while 15 provinces, including Shanxi and Tibet, have fallen into development difficulties due to rigid policies and population outflow. On the whole, the revitalization level of rural talents still faces regional imbalances, structural contradictions and systemic shortcomings, and it is urgent to solve the "Matthew effect" through differentiated approaches and promote the coordinated development of the whole region.

According to the analysis results of the spatiotemporal characteristics of rural talent revitalization, the spatial differentiation and dynamic evolution of the level of rural talent revitalization in China show complex characteristics. The measurement of spatio-temporal differences shows that regional differences are the dominant source of overall differences, and their contribution rate has increased from 56.86% in 2008 to 80.95% in 2022. The overall Gini coefficient decreased from 0.1399 to 0.1271, indicating that although policy interventions alleviated local differences, they failed to fundamentally reverse regional imbalances. Spatial correlation analysis revealed a significant spatial agglomeration effect and the global Moran's I index increased from 0.3363 to 0.5502. The high-value area (H-H type) gradually expanded from the Beijing-Tianjin-Hebei region and the Yangtze River Delta to the hinterland of the Central Plains, forming a contiguous talent highland, while the low-value area (L-L type) spread to the northwest and northeast, the border provinces such as Tibet and Qinghai fell into "low-level lock-in", and the phenomenon of "club convergence" in the east and west intensified. In terms of spatiotemporal evolution, the rightward shift and multimodality of the national kernel density curve indicate that the overall horizontal increase is accompanied by multipolarization, and the centre of gravity of the standard deviation ellipse shifts 172.7 km to the southeast and the azimuth angle is 24 degrees south, reflecting the development momentum tilting towards the eastern coast and the Yangtze River Economic Belt. A 12.5% decrease in the elliptical shape ratio indicates the coexistence of "multi-centre clustering" and "regional convergence" in the spatial reconfiguration. It is worth noting that the northeast region has degenerated from a hot spot to a sub-cold spot, and the western cold spot area has been partially improved but is subject to geographical constraints, exposing the limitations of traditional policy tools in solving the development dilemma west of the "Hu Huanyong Line". On the whole, the spatiotemporal differentiation of rural talent revitalization is the result of the interaction between natural geographical constraints, economic agglomeration effects and policy interventions, and it is urgent to build a cross-regional coordination mechanism and differentiated governance path.

According to the analysis results of the influencing factors of rural talent revitalization, the driving mechanism presents complex characteristics of multi-dimensional and multi-level interaction, which needs to be comprehensively analysed from two aspects: obstacle factor constraints and dynamic influencing factors. The analysis of obstacle factors shows that the national level has long been constrained by three core contradictions: insufficient talent scale, weak innovation ability and lagging construction of the e-commerce platform in rural secondary and tertiary industries, reflecting the deep problems of insufficient adsorption capacity and weak innovation ecology of rural non-agricultural industries. There are significant differences at the regional level: due to the lag in the transformation of traditional industries in northeast China, the scale of rural governance talents and the loss of highly educated talents are superimposed to form a "double collapse"; although the barriers to e-commerce platforms have decreased in the eastern region, the shortage of non-agricultural talents and the low efficiency of agricultural production have highlighted the pressure of industrial upgrading. The western region is limited by geographical conditions, and the proportion of e-commerce infrastructure and highly educated talents continues to be restricted, exposing the vicious circle of "hardware lag - software loss". The central region is faced with the contradiction of disconnection between investment in talent construction and efficiency transformation, and policy dividends have not been fully released. At the provincial level, in 2022, 30 of the 31 provinces were constrained by the scale of rural secondary and tertiary industry talents, while border provinces such as Tibet and Qinghai fell into a low-level equilibrium due to systemic shortcomings, while high-value provinces such as Zhejiang and Jiangsu faced a "high-level trap" due to multiple obstacles. Based on the GTWR model, the analysis of dynamic influencing factors shows that there is significant spatiotemporal heterogeneity in the intensity and direction of each driving factor. The inhibition effect of the urban-rural income gap has been strengthened across the region, and the central and western provinces such as Gansu and Henan have been hit the hardest by the "push-pull effect", which has accelerated the outflow of rural elites. The marginal benefit of rural fixed asset investment is decreasing, and mountainous areas are negatively affected by terrain relief, which leads to the decoupling of capital investment and talent absorption capacity. Rural population density showed a positive effect in Heilongjiang and Liaoning provinces, but failed due to excessive population loss in Gansu. The proportion of inter-provincial migrant workers in Anhui and Henan exacerbated the talent gap, but in Gansu due to the increase in local non-farm employment opportunities, talents are retained or attracted. It is worth noting that the negative impact of environmental pollution has expanded dramatically, and the ecological constraints in economically dense areas such as Beijing-Tianjin-Hebei and Yangtze River Delta have become prominent, while the topographic volatility in mountainous areas such as Guizhou has formed a "geographical stickiness" through characteristic agriculture, partially offsetting the disadvantages of natural conditions.

Based on the above analysis, although the level of rural talent revitalization in China has achieved a significant jump from 2008 to 2022, regional gradient differentiation, spatiotemporal evolution imbalance and structural contradictions are intertwined and coexist, exposing deep-seated development bottlenecks. At the national level, the core constraints are the insufficient release of talent construction efficiency, the weak adsorption capacity of non-agricultural industries and the lag of innovation ability. At the regional level, the "high value polarization" in the east, the "low-level lock-in" in the west, the "sluggish transformation" in the northeast and the "disconnection in efficiency transformation" in the central part highlight the differentiation of development momentum. In terms of the spatial and temporal dimensions, the "strong in the east and weak in the west" pattern has become entrenched, while the "multi-centre agglomeration - edge collapse" phenomenon coexists. This reflects the combined impact of the imbalance among natural geographical constraints, economic agglomeration effects, and policy interventions.At the same time, the widening income gap between urban and rural areas, the intensification of negative environmental externalities, and the inefficiency of factor allocation have further exacerbated the "Matthew effect" and "club convergence", resulting in the "upgrading bottleneck" in the high-value area and the "system shortcoming" in the low-value area. In this context, how to solve regional imbalances, activate endogenous power, and optimize the synergy of factors through differentiated policy design has become a key proposition to promote the transformation of rural talent revitalization from "scale expansion" to "quality and efficiency together".

6.2. Countermeasures and Suggestions

Based on the results of the measurement of the level of rural talent revitalization, the characteristics of spatiotemporal differentiation and the analysis of influencing factors, it is necessary to construct a differentiated policy system from multiple dimensions to promote the optimization of the rural talent ecology in the whole region in view of the core problems such as regional imbalance, structural contradictions and systemic shortcomings. Specific suggestions are made below.

(1) Establish a regional coordinated development mechanism to solve the dilemma of gradient differentiation

In view of the spatial differentiation characteristics of high-value polarization in the east and low-level lock-in in the west, it is necessary to innovate the model of "cross-regional compensation of talent elements", set up "western talent innovation enclaves" in developed regions such as the Yangtze River Delta and the Pearl River Delta, and guide enterprises in the east to migrate smart agriculture R&D centres and e-commerce training bases to Chengdu-Chongqing and central Yunnan through mechanisms such as tax sharing and technology shareholding, so as to realize the deep integration of "eastern capital technology + western application scenarios". The essence of high-value polarization in the east and low-level lock-in in the west is the result of the superposition of the "siphon effect" and the "crowding out effect" of talent factors. Through the establishment of the "western talent innovation enclave" and supporting tax sharing, technology shareholding and other systems, the essence is to build a cross-regional value chain of "factor investment, value creation, and income feedback". Enterprises in the eastern region will move their R&D and training functions to the west, which can not only use the low-cost factors in the west to reduce the cost of innovation trial and error, but also obtain long-term benefits through technology shareholding. In the western region, the accumulation of local human capital is accelerated by undertaking technological spillovers, and at the same time, external resources are converted into local infrastructure investment by relying on the tax sharing mechanism, forming a "space for time" development buffer zone. This two-way reciprocal mechanism can break through the one-way blood transfusion model of traditional counterpart assistance and establish a sustainable factor convection channel under the market-oriented framework. The "Yongzhou Talent Enclave" jointly built by Ningbo and Daishan County of Zhoushan has realized mutual recognition of high-level talents between the two places, and promoted the coordinated development of new petrochemical materials, offshore equipment and other industries through the "Twin Cities Sharing" policy (such as the exchange of public services such as talent apartments, medical care and education). For example, Zhoushan enterprises set up a R&D centre in Ningbo to enjoy Ningbo's talent resources, while Daishan provides production scenarios, forming a closed loop of "R&D in the enclave and production in the local".

For the problem of sluggish industrial transformation in northeast China, we can promote Shenyang, Changchun and the eastern coast to jointly build a "special zone for the revitalization of old industrial bases", focusing on undertaking technology spillovers in the fields of equipment manufacturing and biological breeding, supporting "talent return credit loans", and giving land use to talents returning to their hometowns to start businesses. The sluggish industrial transformation in the northeastern region is attributed to the vicious cycle of path dependence of traditional industries and insufficient supply of new factors. The essence of promoting the joint construction of a "special talent zone" between the old industrial base and the eastern part of the country is to realize the dislocation and connection between the industrial chain and the talent chain through the redivision of regional functions. The expected mechanism is that the eastern coast will release mature technology, management experience and other high-level elements, while the northeast region can rely on the existing industrial base to transform into a technology transformation testing ground. By building a circular mechanism of "technology spillover→ scenario application → income feedback", it can not only activate the "learning by doing" effect of local talents, but also attract external talents with factor price differences, forming a "catfish effect", and ultimately promoting the industrial structure from "low-end lock-in" to "mid-to-high-end". By constructing a circular mechanism of "technology spillover→ scenario application → revenue feedback", it can not only activate the "learning by doing" effect of local talents, but also attract external talents through factor price differences to form a "catfish effect", and ultimately promote the industrial structure from "low-end lock-in" to "mid-to-high-end jump".

Border provinces need to implement the "Geographical Constraint Breaking Project", pilot the "Plateau Characteristic Talent Revitalization Program" in Tibet and Qinghai, cultivate local talents in eco-tourism planning and ethnic cultural creativity, and transform talent efficiency into infrastructure investment capital through the policy of "contribution points for resources", so as to break the trap of "low-level equilibrium". The root cause of the dilemma of "low-level equilibrium" in the border provinces lies in the mismatch between the input of external resources and the local carrying capacity, which leads to the obstruction of the channel for the transformation of talent efficiency. The underlying logic of the policy of "exchanging contribution points for resources" is to establish an endogenous growth model of "human capital investment→ efficiency output→ capital accumulation". By quantifying the contribution of talents in the fields of ecological protection and cultural inheritance into tradable "development right points", the essence is to transform the abstract talent efficiency into concrete infrastructure construction capital. This not only avoids the misallocation of resources that may be caused by traditional fiscal transfer payments, but also guides talent activities to be deeply bound to regional characteristic endowments through quantitative incentives, forming a positive feedback loop of "talent growth → regional development → environment improvement". At the same time, the strategy of cultivating local talents instead of simply introducing foreign elites can effectively reduce the cost of talent adaptation under geographical constraints and enhance the sustainability of the development model.

(2) Strengthen the coordination between non-agricultural industries and talent chains, and reverse structural contradictions

Focusing on the core obstacle of insufficient talent scale in rural secondary and tertiary industries, it is necessary to build a "talent matrix for characteristic industries" at the county level, focus on emerging occupational groups such as digital agricultural engineers and smart logistics managers in the east, cultivate technical teams for intensive processing of agricultural products in the central region, and develop talent clusters for green health care industries in the west. The essence of the shortage of talents in the secondary and tertiary industries in rural areas is the "low-end lock-in" caused by the mismatch between the industrial energy level and the quality of human capital. Taking the county as the unit to build a "talent matrix for characteristic industries" is to reconstruct the matching efficiency of the industrial chain and the talent chain through spatial stratification. The deployment of high-level talents such as digital agricultural engineers in the eastern region is a response to the advantages of its digital economy infrastructure. The central part of the country focuses on the agricultural product processing technology team, aiming to activate the raw material advantages and labour cost advantages of the main grain producing areas. The cultivation of green health care talent clusters in the western region is to transform the ecological resource endowment into a human capital development orientation. This differentiated layout breaks the traditional "one-size-fits-all" model of talent recruitment. By precisely matching the comparative advantages of industries with the skills and characteristics of talents, it forms an enhanced loop of "upgrading industries drives improvement in talent quality - talent concentration feeds back to the leap in industrial level".

In view of the lagging development of e-commerce platforms, it is recommended to implement the "Digital Business Revitalization of Agriculture 2.0 Project", build a county-level e-commerce big data center and cloud warehousing and logistics hub, and implement dual-track incentives for agricultural product anchors that combine "skill certification" and "traffic support". For example, the construction of "ASEAN cross-border live broadcast base" in the border area of Guangxi, and the cultivation of small language e-commerce operation talents. Pengzhou Human Resources Industrial Park in Sichuan Province cooperated with Douyin to establish a digital marketing talent certification centre, trained more than 1,000 e-commerce anchors, and achieved certification through the "one test and two certificates" system. The root cause of the lag of e-commerce platforms lies in the conductive blockage of "lack of infrastructure, skill faults, and market access barriers" in the rural digital economy. The "Digital Commerce and Agriculture 2.0 Project" is essentially to build a new production function of "data elements × human capital" through the construction of county-level e-commerce big data centres and cloud storage hubs. The real-time analysis ability of the big data centre on consumer demand can penetrate the information barrier of the traditional industrial chain and accurately guide the iteration direction of talent skills. The physical network extension of the cloud warehousing and logistics system expands the radiation radius of talent efficiency by reducing transaction costs. The design of the dual-track incentive of "skill certification + traffic support" is essentially to establish a human capital quality signal transmission mechanism on the supply side and open up the flow channel for talent value realization on the demand side, thus forming a closed loop of "data-driven→ skill certification → market feedback", which can systematically improve the effectiveness of the e-commerce talent supply.

It is also proposed to establish an innovative "revolving door for urban and rural talents" mechanism, establish a provincial-level rural revitalization consultant expert database, allow scientific researchers to lead rural projects through "unveiling the leader", and give collective asset income distribution rights to urban professionals who have served for three consecutive years, so as to solve the problem of weak adsorption capacity of non-agricultural industries. The core crux of the weak adsorption capacity of non-agricultural industries lies in the "one-way pumping" effect in the exchange of urban and rural factors. The innovation of the "revolving door of urban and rural talents" mechanism breaks down the institutional barriers to talent flow through the reconstruction of property rights and the compatible design of incentives. Allowing scientific researchers to lead projects is a "policy guide" for introducing urban intellectual resources into rural areas, and its essence is to reduce the transaction cost of talent sinking through task contractualization. Giving talents the right to benefit from collective assets at the end of their service period is to build a benefit binding mechanism of "human capital property rights" and transform short-term services into long-term rights and interests. This combination of "identity flexibility and rights and interests" not only avoids the drawbacks of traditional talents going to the countryside, but also stimulates the endogenous motivation of talents to take root in the countryside through property rights incentives, and finally forms a spiral upward channel between urban and rural areas of "knowledge and technology going to the countryside, economic returns to the city, and human capital precipitation".

(3) Activate the innovation ecology and policy efficiency, and break through systemic shortcomings

In view of the weak innovation ability and policy rigidity, it is necessary to create a "rural science and technology innovation incubator" in the main agricultural production areas, provide direct subsidies or tax credits for R&D expenditures in priority fields such as intelligent agricultural machinery and biological seed technology, implement the "science and technology correspondent +" model in the villages, and form an innovation consortium between university scientific research teams and new business entities. The fundamental weakness of rural innovation lies in the structural predicament where innovation elements are both "islandized" and "fragmented" simultaneously.Through the "Ten AI Talents" policy, Wuxi provides project funding of up to 100 million yuan for top talents, and promotes joint training between schools and enterprises to accelerate technology transformation. Rural production areas can learn from this model to give additional subsidies to the research and development of intelligent agricultural machinery to attract urban scientific and technological resources to the countryside. The creation of a "rural science and technology innovation incubator" and the provision of R&D fiscal incentives are in essence to reconstruct the spatio-temporal allocation model of innovation elements through policy levers. The preferential tax treatment for R&D expenses forms a "cost depression effect" to attract the directional flow of urban scientific and technological resources to the main agricultural producing areas. The "science and technology correspondent + innovation consortium" model reduces the transaction cost of technology transformation through contractual collabouration. This combination strategy can break through the organizational boundary constraints in traditional industry-university-research cooperation, and form a dynamic balance of "magnetic attraction effect" and "radiation effect" of innovation elements in rural fields.

In ecologically fragile areas, the "carbon sink-talent replacement" mechanism will be piloted, and part of the carbon sink income will be injected into the "ecological talent fund" to reward the entrepreneurial teams returning to their hometowns who participate in ecological governance. The crux of the talent dilemma in ecologically fragile areas lies in the mismatch between the positive externalities of ecological protection and individual benefits. The "carbon sink-talent replacement" mechanism builds a closed-loop loop of "ecological protection investment→ carbon sink income accumulation→ talent incentive feedback" by capitalizing the results of ecological product value accounting. The design of injecting carbon sink income into the talent fund in proportion is essentially to transform the abstract ecological value into quantifiable talent development resources, which not only solves the problem of sustainable financing of ecological governance, but also guides talent activities to resonate with ecological goals at the same frequency through economic incentives, so that geographically disadvantaged areas can obtain differentiated competitive advantages.

At the governance level, a "digital twin policy simulation system" should be built to monitor the trend of talent flow and the marginal benefits of policies in various provinces in real time, and dynamically adjust the intensity of talent introduction and cultivation in northeast China and the priority of infrastructure investment in the western region. For areas with serious brain drain from highly educated talents, it is necessary to implement the policy of "returning to their hometowns to start a business" to integrate core demands such as homestead use rights and children's education guarantees. Policy rigidity stems from the time lag and distortion of the chain of "decision-making→ implementation→ feedback" in traditional governance. The "Digital Twin Policy Simulation System" uses big data modeling and machine learning technology to build a closed-loop of "forward-looking rehearsal→ real-time monitoring→ and dynamic optimization" of policy intervention. The real-time monitoring of talent flow trends and policy marginal benefits is essentially to upgrade the policy process from "experience-driven" to "data-driven", and analyse the interaction effects of multiple factors through parametric models, so that the decision-making basis for governance talent introduction and cultivation intensity in northeast China and the priority of infrastructure investment in the west can be shifted from qualitative judgement to quantitative deduction. The supporting policy of "returning to the hometown to start a business rights package" is to integrate discrete policy tools such as homestead use rights and education security into a "human capital investment group" through the design of property rights subdivision and an equity portfolio, and use option thinking to lock in the long-term value of talents, and solve the contradiction between short-term policy incentives and talent development cycle.

6.3. Research Deficiencies and Prospects

Although this study has systematically revealed the spatiotemporal differentiation characteristics and driving mechanisms of rural talent revitalization by constructing a multi-dimensional evaluation system and using spatiotemporal analysis methods, there are still several limitations that need to be further explored. At the data level, due to the constraints of statistical means and the availability of indicators, some indicators (such as the number of "three branches and one support" personnel and the scale of active online stores in Taobao Village) adopt mixed measurement methods. Although the data integrity is improved by use of the imputation method and industry conversion coefficient, it may still weaken the explanatory power of micro individual behavior differences to macro trends. Due to the lack of early data, similar regional interpolation may be difficult to use to fully reflect the uniqueness of talent development in the special geographical and cultural environment. At the theoretical level, although the study constructs a three-dimensional analytical framework of "security-construction-efficiency", it does not characterize the dynamic impact of institutional barriers such as the household registration system and land transfer in the flow of urban and rural factors, and fails to deeply analyse the nonlinear relationship between the policy time lag effect and spatial spillover. In addition, the analysis of influencing factors focuses on explicit variables such as economic drivers and natural constraints, and the mechanism of implicit factors such as local cultural identity and social relationship networks has not been fully explored.

Future research can be deepened and expanded in three aspects: 1) build a multi-source data fusion analysis framework, integrate new data sources such as satellite remote sensing, mobile phone signaling, and social media, and capture the trajectory and spatial behavior characteristics of rural talent flow in real time, and break the static and lagging limitations of traditional statistical data. 2) Explore an interdisciplinary research paradigm from the perspective of complex systems, integrate rural talent revitalization into the "natural-economic-social" composite ecosystem, and couple system dynamics models and machine learning algorithms to simulate the spatio-temporal response of talent elements under different policy scenarios. 3) Strengthen the dynamic monitoring and effectiveness evaluation of rural revitalization strategies, establish a multi-scale monitoring network covering "counties, villages, towns, and communities", and focus on tracking the long-term effects of emerging drivers such as digital technology empowerment and institutional innovation pilots. At the same time, it is necessary to strengthen international comparative research, systematically summarize the lessons and lessons of rural human capital improvement in developed countries, and explore cross-border talent cooperation models in combination with the Belt and Road Initiative, so as to contribute Chinese wisdom to the sustainable development of global rural areas. Finally, through theoretical deepening and method innovation, the paradigm transformation of rural talent revitalization research from "phenomenon description" to "mechanism analysis" and from "policy response" to "governance innovation" will be promoted, so as to provide more solid academic support for the realization of urban-rural integration development and common prosperity.

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Appendix

I. Record the Source of Indicator Data

Model	Primary Data Source
Number of Family Farms	China Rural Management Statistical Yearbook & China Rural Cooperative Economy Statistical Annual Report
Farmer Cooperatives	
Number of Rural labourers Working Outside Townships but Within Counties	China Rural Management Statistical Yearbook & China Rural Policy and Reform Statistical Annual Report
Number of Inter-provincial Migrant Workers	
Total Number of Migrant Workers	
Rural Population	Local Statistical Bulletins on National Economic and Social Development
Expenditure for Agriculture, Forestry, and Water Conservancy	Local Statistical Yearbooks
General Budget Expenditure	
Fiscal Expenditure on Social Security and	

Model	Primary Data Source
Employment	
Gross Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery	
Number of Agricultural Invention Patent Applications	National Intellectual Property Administration (Patent Classification A01 search)
Regional Gross Domestic Product (GDP)	China Finance Yearbook
Village Construction Area	
Rural Park Green Space Area	China Urban-Rural Construction Statistical Yearbook
Rural Construction Area	
Number of Rural Construction Personnel	
SO_2 Emission Volume	China Environmental Statistical Yearbook
Number of Rural Teachers	China Education Statistical Yearbook
Full-time Equivalent of R&D Personnel	China Statistical Yearbook on Science and Technology
Total Power of Agricultural Machinery	
Crop Cultivation Area	
Output Value of Agricultural Products	China Rural Statistical Yearbook
Value-added of Agriculture	
Number of Rural Employed Persons	
Total Number of Rural Households	China Population and Employment Statistical Yearbook
Number Employed in Rural Private Enterprises	
Rural Population by Educational Attainment	
Per Capita Disposable Income of Rural Residents	
Total Food Expenditure of Rural Residents	
Total Consumption Expenditure of Rural Residents	China Social Statistical Yearbook
Per Capita Disposable Income of Rural Residents	
Number of Broadband Access Households	China Statistical Yearbook
Rural Mail Delivery Routes	China Statistical Yearbook
Per Capita Rural Fixed Asset Investment	China Statistical Yearbook
Number of Rural Health Personnel	China Health Statistics Yearbook
Number of Leading Agricultural Enterprises	Public Announcement Documents, Ministry of Agriculture and Rural Affairs

Model	Primary Data Source
	of the People's Republic of China

II. Number of Taobao Villages Source

Alibaba Research has released the "China Taobao Village Research Report" every year since 2013, which systematically collects the directory and development data of Taobao villages across the country. The institute is a professional research institution under the Alibaba Group and is responsible for formulating and maintaining Taobao Village certification standards. The data is obtained through the official website of Ali Research Institute, the official WeChat public account, and authoritative media release channels, ensuring the authority and timeliness of the data.

II.1 Data Sources

Alibaba Research Institute's "China Taobao Village Research Report" series, including annual reports from 2013 to 2022.

https://swt.fj.gov.cn/xxgk/jgzn/jgcs/sctxjsc/gzdt_386/202212/t20221219_6081123.htm

https://finance.sina.cn/tech/2020-10-20/detail-iiznezxr6918568.d.html?fromtech=1

II.2 Mode of Acquisition

- Official website: http://www.aliresearch.com
- Official WeChat public account: Alibaba Research Institute
- Contact email: aliresearch@alibaba-inc.com

III. Some Figures Codes

Figure 3.5: Heat map of the Rural Talent Revitalization Index in four regions, 2008-2022

```
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
```

```python
from matplotlib import rcParams

# Set global fonts
# Use SimSun for Chinese, Times New Roman for numbers and English
rcParams['font.family'] = 'SimSun'  # Set Chinese font to SimSun
rcParams['font.sans-serif'] = ['SimSun']  # Set sans-serif font to SimSun
rcParams['mathtext.fontset'] = 'stix'  # Set math formula font to STIX (consistent with Times New Roman style)

# Explicitly set Seaborn font
sns.set(font="SimSun")

# Prepare data
data = {
    "region": ["Northeast", "East", "West", "Central"],
    "2008": [0.0383, 0.0601, 0.0274, 0.0335],
    "2009": [0.0434, 0.0646, 0.0324, 0.0379],
    "2010": [0.0462, 0.0701, 0.0356, 0.0420],
    "2011": [0.0505, 0.0768, 0.0404, 0.0479],
    "2012": [0.0556, 0.0828, 0.0451, 0.0533],
    "2013": [0.0622, 0.0898, 0.0500, 0.0551],
    "2014": [0.0695, 0.0970, 0.0564, 0.0627],
    "2015": [0.0732, 0.1031, 0.0616, 0.0674],
    "2016": [0.0712, 0.1093, 0.0641, 0.0694],
    "2017": [0.0744, 0.1161, 0.0692, 0.0733],
    "2018": [0.0780, 0.1226, 0.0741, 0.0781],
    "2019": [0.0832, 0.1290, 0.0787, 0.0822],
    "2020": [0.0946, 0.1425, 0.0868, 0.0919],
    "2021": [0.1041, 0.1539, 0.0940, 0.0996],
    "2022": [0.1107, 0.1645, 0.0988, 0.1052]
}

# Convert to DataFrame
df = pd.DataFrame(data)
df.set_index("region", inplace=True)

# Draw heatmap
```

```python
plt.figure(figsize=(12, 6))
heatmap = sns.heatmap(
    df,
    annot=True,
    cmap="YlOrRd",
    fmt=".4f",
    linewidths=0.5,
    annot_kws={"fontsize": 12, "fontfamily": "Times New Roman"}  #
Set heatmap annotation font to Times New Roman
)

# Add title and labels
plt.xlabel("Year", fontsize=14, fontproperties="SimSun")
plt.ylabel("Region", fontsize=14, fontproperties="SimSun")

# Set axis tick font to Times New Roman
plt.xticks(fontname="Times New Roman", fontsize=14)
plt.yticks(fontname="SimSun", fontsize=14)

# Display the chart
plt.tight_layout()
plt.show()
```

Figure 3.9: Changes in the ranking of provinces from 2008 to 2022

```python
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
from matplotlib import rcParams

# Set global fonts
# Use SimSun for Chinese, Times New Roman for numbers and English
rcParams['font.family'] = 'SimSun'  # Set Chinese font to SimSun
rcParams['font.sans-serif'] = ['SimSun']  # Set sans-serif font to
SimSun
rcParams['mathtext.fontset'] = 'stix'  # Set math formula font to
STIX (consistent with Times New Roman style)

# Explicitly set Seaborn font
```

```
sns.set(font="SimSun")

# Prepare data
data = {
    "地区": ["Northeast", "East", "West", "Central"],
    "2008": [0.0383, 0.0601, 0.0274, 0.0335],
    "2009": [0.0434, 0.0646, 0.0324, 0.0379],
    "2010": [0.0462, 0.0701, 0.0356, 0.0420],
    "2011": [0.0505, 0.0768, 0.0404, 0.0479],
    "2012": [0.0556, 0.0828, 0.0451, 0.0533],
    "2013": [0.0622, 0.0898, 0.0500, 0.0551],
    "2014": [0.0695, 0.0970, 0.0564, 0.0627],
    "2015": [0.0732, 0.1031, 0.0616, 0.0674],
    "2016": [0.0712, 0.1093, 0.0641, 0.0694],
    "2017": [0.0744, 0.1161, 0.0692, 0.0733],
    "2018": [0.0780, 0.1226, 0.0741, 0.0781],
    "2019": [0.0832, 0.1290, 0.0787, 0.0822],
    "2020": [0.0946, 0.1425, 0.0868, 0.0919],
    "2021": [0.1041, 0.1539, 0.0940, 0.0996],
    "2022": [0.1107, 0.1645, 0.0988, 0.1052]
}

# Convert to DataFrame
df = pd.DataFrame(data)
df.set_index("地区", inplace=True)

# Draw heatmap
plt.figure(figsize=(12, 6))
heatmap = sns.heatmap(
    df,
    annot=True,
    cmap="YlOrRd",
    fmt=".4f",
    linewidths=0.5,
    annot_kws={"fontsize": 12, "fontfamily": "Times New Roman"}  #
Set heatmap annotation font to Times New Roman
)

```

```
# Add title and labels
plt.xlabel("Year", fontsize=14, fontproperties="SimSun")
plt.ylabel("Region", fontsize=14, fontproperties="SimSun")

# Set axis tick font to Times New Roman
plt.xticks(fontname="Times New Roman", fontsize=14)
plt.yticks(fontname="SimSun", fontsize=14)

# Display the chart
plt.tight_layout()import matplotlib.pyplot as plt
import pandas as pd

# Set Matplotlib to support Chinese
plt.rcParams['font.sans-serif'] = ['SimHei']  # Use SimHei font
plt.rcParams['axes.unicode_minus'] = False  # Solve the problem of
negative sign display
# Data
data = {
    "省份": ["Anhui", "Beijing", "FUjian", "Gansu", "Guangdong",
"Guangxi", "Guizhou", "Hainan", "Hebei", "Henan",
             "Heilongjiang", "Hubei", "Hunan", "Jinan", "Jiangsu",
"Jiangxi", "Liaoning", "Inner Mongolia", "Ningxia",
             "Qinghai", "Shandong", "Shanxi", "Shaanxi",
"Shanghai", "Sichuan", "Tianjin", "Tibet", "Xinjiang", "Yunnan",
"Zhejiang", "Chongqing"],
    "排名变化": [14, -1, 11, -5, 4, 5, -1, 7, -1, 14, -6, 3, 6, -6,
9, -2, -6, -9, 0, -6, 1, -17, 1, 1, 3, -5, -12, -9, -4, 1, 10]
}

# Create DataFrame
df = pd.DataFrame(data)

# Sort data for better display
df = df.sort_values(by="排名变化", ascending=False)

# Create color mapping
colors = plt.cm.RdYlGn((df["排名变化"] - df["排名变化"].min()) / (df["
排名变化"].max() - df["排名变化"].min()))
```

```
# Draw bar chart
fig, ax = plt.subplots(figsize=(10, 8))
bars = ax.barh(df["省份"], df["排名变化"], color=colors)

# Add title and labels
ax.set_xlabel("Ranking changes", fontsize=14)
ax.set_ylabel("Province", fontsize=14)

# Add colorbar to show color mapping
sm = plt.cm.ScalarMappable(cmap=plt.cm.RdYlGn,
norm=plt.Normalize(vmin=df["排名变化"].min(), vmax=df["排名变化
"].max()))
sm.set_array([])
plt.colorbar(sm, ax=ax, label="Change in ranking value")  # Specify
ax parameter
# Display the chart
plt.tight_layout()
plt.show()
plt.show()
```

Figure 4.3: Kernel density estimation curve of the National Rural Talent Revitalization Index

```
function [Max_Value,Min_Value,T,X] =
N_density(begin_year,xx,yy,zz,X)

%UNTITLED A summary of this function is shown here
[N,T] = size(X);
Year_0 = begin_year; % Starting year, need to be modified according
to the actual starting year of the original data.
Year_1 = Year_0+T-1;

%% Calculate kernel density estimation values for each year and plot.
figure(1)
for i = 1:T
     f(:,i) = ksdensity(X(:,i));
     plot(f)
     hold on
```

```
end
j = 0;
for i = Year_0:Year_1
      j = j+1;
      str{j} = char([num2str(i),'year']); % Adjust year unit to English
end
legend(str)
f = f';

%% Determine the X-axis and Y-axis scales for the 3D kernel density estimation plot.
Min_Value = min(min(X));
Max_Value = max(max(X));
M = length(f);
x = linspace(Min_Value,Max_Value,M);
y = Year_0:Year_1;
[x,y] = meshgrid(x,y);

%% Plot the 3D kernel density estimation results
figure(2) % This plot can be manually rotated in 3D.
mesh(x,y,f)
xlabel(xx);
ylabel(yy);
zlabel(zz);
end
```

```
%% Ensure MATLAB R2021a or a higher version is installed
% If installed, only need to modify the following necessary parameters.
clc
Clear

%% Data file path and parameter settings (parameters to be modified below)
cd('E:\水平衡社会时间序列数据\Kernel 密度估计\二维核密度估计全样本数据');
% Path needs to be modified according to actual situation
```

```
X = xlsread('核密度数据.xlsx'); % File name needs to be modified
according to actual situation
begin_year = 2008 ; % Starting year data, needs to be modified according
to actual situation
xx = 'Water Resource Utilization Efficiency'; % X-axis label, needs
to be modified according to actual situation
yy = 'Year'; % Y-axis label, generally no need to modify
zz = 'Kernel Density Estimation Value'; % Z-axis label, generally no
need to modify
%% Call the kernel density estimation module
[Max_Value,Min_Value,T,X] = N_density(begin_year,xx,yy,zz,X)
```

Figure 4.8: Local Moran scatter plots of rural talent revitalization (2008, 2015 and 2022)

```
**Moran's I index calculation
xtset id year  // Set panel data format, with id as individual
identifier and year as time identifier
spatwmat using W.dta, n(W) standardize  // Load spatial weight matrix
data W.dta, name the weight matrix W and standardize it
preserve  // Save the current data state
keep if year==2004      // Keep data for 2004 (year can be modified)
spatgsa y,weights(W) moran geary twotail  // Calculate Moran's I
index and Geary index for variable y, using two-tailed test
restore  // Restore data to the state before preservation

// Loop to calculate Moran's I index for each year from 2004 to 2016
forvalue i  = 2004/2016{
    preserve  // Save the current data state
    keep if year==`i'  // Keep data for year `i'
    spatgsa y,weights(W) moran twotail  // Calculate Moran's I index
for variable y in this year, using two-tailed test
    restore  // Restore data state
}

**Moran scatter plot drawing
preserve  // Save the current data state
keep if year==2004      // Keep data for 2004 (year can be modified)
splagvar y , wname(W) wfrom(Stata) moran(y) plot(y)  // Calculate
spatial lag of y based on weight matrix W and draw Moran scatter plot
```

```
restore  // Restore data state
```

Figure 5.1: Obstacle degree of the indicator layer for rural talent Revitalization (%) for 2008, 2015 and 2022

```
import matplotlib.pyplot as plt
import numpy as np
import matplotlib

matplotlib.rcParams['font.sans-serif'] = ['SimHei', 'Microsoft
YaHei', 'DejaVu Sans']
matplotlib.rcParams['axes.unicode_minus'] = False

labels = ['A1', 'A2', 'A3', 'B1', 'B2', 'C1', 'C2', 'C3']
num_vars = len(labels)

data_2008 = [14.02817442, 4.025222393, 14.6109679, 31.73831926,
6.291275265, 14.38829667, 7.881522251, 7.036221848]
data_2015 = [15.64099857, 4.224647977, 13.75144228, 31.07324016,
6.294558918, 14.0238601, 8.140308292, 6.850943706]
data_2022 = [14.32200645, 4.8708049, 11.48174131, 31.05986423,
7.133491954, 14.35370183, 9.547695211, 7.230694109]

angles = np.linspace(0, 2 * np.pi, num_vars, endpoint=False).tolist()

def prepare_data(data):
data = list(data) + data[:1]
return data

angles_plot = angles + angles[:1]
data_2008_plot = prepare_data(data_2008)
data_2015_plot = prepare_data(data_2015)
data_2022_plot = prepare_data(data_2022)

fig, axes = plt.subplots(1, 3, figsize=(18, 6),
subplot_kw=dict(projection='polar'))

years_data = [
    ('2008年', data_2008_plot, axes[0]),
```

```
    ('2015 年', data_2015_plot, axes[1]),
    ('2022 年', data_2022_plot, axes[2])
]

line_color = 'blue'
line_style = '-'

for i, (year, data, ax) in enumerate(years_data):

    ax.plot(angles_plot, data, color=line_color,
linestyle=line_style, linewidth=2.5, label=year)
    ax.fill(angles_plot, data, color=line_color, alpha=0.15)
    ax.set_xticks(angles)
    ax.set_xticklabels(labels, fontsize=11)
    ax.set_ylim(0, 35)
    ax.set_yticks([0, 10, 20, 30])
    ax.set_yticklabels(['0', '10', '20', '30'], fontsize=9)
    ax.grid(True, linestyle='--', alpha=0.5)
    ax.legend(loc='upper right', fontsize=11)
    ax.set_title(f'{year}', fontsize=14, fontweight='bold', pad=15)
plt.tight_layout()
plt.show()
```

Figure 5.3: Trend of regression coefficients in the GTWR model from 2008 to 2022

```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

# Solve the problem of English display
plt.rcParams['font.sans-serif'] = ['Times New Roman']  # Set English font
plt.rcParams['axes.unicode_minus'] = False  # Solve the problem of negative sign
display

# Complete data entry
data =  {
    'year':
[2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022
```

```
],
    'Anhui':
[0.2297,0.2140,0.1953,0.1625,0.0782,-0.0971,-0.3048,-0.4647,-0.5852,-0.7075
,-0.8789,-1.0377,-1.1315,-1.1844,-1.1999],
    'Beijing':
[0.1708,0.1525,0.1324,0.0981,0.0094,-0.1546,-0.3366,-0.4742,-0.5857,-0.7163
,-0.9264,-1.2911,-1.6155,-1.8484,-2.0588],
    'Fujian':
[0.2644,0.2587,0.2515,0.2363,0.1757,0.0143,-0.2086,-0.3906,-0.5164,-0.6144,
-0.6991,-0.6804,-0.5776,-0.4443,-0.2042],
    'Gansu':
[0.0789,0.0697,0.0436,-0.0707,-0.2601,-0.3181,-0.2943,-0.2464,-0.2251,-0.23
63,-0.3189,-0.4496,-0.4353,-0.4962,-0.4624],
    'Guangdong':
[-0.0654,-0.0586,-0.0533,-0.0515,-0.0598,-0.0838,-0.1227,-0.1642,-0.2051,-0
.2572,-0.3459,-0.4718,-0.5879,-0.6833,-0.7895],
    'Guangxi':
[-0.0339,-0.0444,-0.0593,-0.0809,-0.1095,-0.1338,-0.1567,-0.1822,-0.2068,-0
.2309,-0.2544,-0.2849,-0.3234,-0.3608,-0.3858],
    'Guizhou':
[0.1141,0.0998,0.0880,0.0654,-0.0037,-0.1373,-0.2833,-0.3973,-0.4936,-0.610
1,-0.8093,-1.2501,-1.7395,-2.0927,-2.4293],
    'Hainan':
[0.0992,0.0694,0.0308,-0.0279,-0.1275,-0.2627,-0.3817,-0.4679,-0.5614,-0.73
34,-1.1251,-1.7738,-2.2490,-2.4410,-2.5925],
    'Hebei':
[0.1966,0.1824,0.1746,0.1563,0.0724,-0.1111,-0.3101,-0.4602,-0.5853,-0.7112
,-0.8517,-0.9046,-0.7543,-0.5712,-0.3245],
    'Henan':
[0.2190,0.2051,0.1918,0.1678,0.0875,-0.0888,-0.3028,-0.4701,-0.5999,-0.7197
,-0.8390,-0.9013,-0.8488,-0.7742,-0.6236],
    'Heilongjiang':
[0.3435,0.3577,0.3744,0.3851,0.3595,0.2635,0.1078,-0.1037,-0.2921,-0.3444,-
0.1849,0.2375,0.8379,1.5399,2.4823],
    'Hubei':
[-0.0924,-0.1102,-0.1422,-0.1978,-0.2955,-0.4092,-0.4796,-0.5334,-0.6153,-0
.7862,-1.2196,-2.0648,-2.6909,-3.0000,-3.2770],
    'Hunan':
```

```
[-0.0089,-0.0166,-0.0293,-0.0497,-0.0845,-0.1315,-0.1809,-0.2341,-0.3010,-0
.4131,-0.6482,-1.0252,-1.3282,-1.4656,-1.5817],
    'Jilin':
[0.2486,0.2533,0.2562,0.2492,0.2063,0.0846,-0.1111,-0.2795,-0.3650,-0.3888,
-0.3768,-0.3355,-0.3084,-0.2730,-0.1919],
    'Jiangsu':
[0.1556,0.1300,0.0960,0.0460,-0.0421,-0.1722,-0.2994,-0.3965,-0.4883,-0.623
8,-0.8793,-1.2312,-1.4686,-1.5799,-1.6753],
    'Jiangxi':
[-0.1202,-0.1362,-0.1697,-0.2341,-0.3476,-0.4466,-0.4872,-0.5324,-0.6288,-0
.7530,-0.9881,-1.5170,-2.0468,-2.4184,-2.8244],
    'Liaoning':
[0.3198,0.3321,0.3477,0.3598,0.3499,0.2618,0.0623,-0.1544,-0.2845,-0.2839,-
0.1109,0.2481,0.6357,0.9912,1.4185],
    'Neimenggu':
[0.3039,0.3059,0.3091,0.3030,0.2396,0.0657,-0.1573,-0.3373,-0.4616,-0.5394,
-0.5000,-0.2292,0.1904,0.6923,1.4274],
    'Ningxia':
[0.1425,0.1272,0.1148,0.0908,0.0157,-0.1341,-0.3022,-0.4339,-0.5438,-0.6652
,-0.8384,-1.1519,-1.4241,-1.6255,-1.8262],
    'Qinghai':
[0.2030,0.1930,0.1858,0.1778,0.1523,0.0736,-0.0678,-0.2290,-0.3560,-0.4005,
-0.3012,0.0377,0.3709,0.4614,0.5603],
    'Shandong':
[0.1482,0.1304,0.1123,0.0808,-0.0023,-0.1577,-0.3280,-0.4564,-0.5612,-0.689
8,-0.9099,-1.3548,-1.7773,-2.0881,-2.3826],
    'Shanxi':
[-0.0430,-0.0415,-0.0423,-0.0484,-0.0654,-0.0932,-0.1279,-0.1607,-0.1865,-0
.2039,-0.2099,-0.2237,-0.2700,-0.3240,-0.3708],
    'Shaanxi':
[0.2984,0.3228,0.3399,0.3654,0.4498,0.4864,0.2492,-0.0881,-0.3196,-0.4501,-
0.4646,-0.1026,0.1317,0.0903,-0.1764],
    'Shanghai':
[0.0713,0.0486,0.0184,-0.0262,-0.1002,-0.1992,-0.2897,-0.3620,-0.4463,-0.59
61,-0.9100,-1.3941,-1.7329,-1.8492,-1.9402],
    'Sichuan':
[0.0202,0.0140,0.0044,-0.0108,-0.0416,-0.0952,-0.1601,-0.2160,-0.2660,-0.33
20,-0.4426,-0.5957,-0.7227,-0.8327,-0.9388],
```

```
    'Tianjin':
[0.0220,-0.0071,-0.0455,-0.1007,-0.1875,-0.2902,-0.3684,-0.4256,-0.5032,-0.
6706,-1.0711,-1.7481,-2.2259,-2.3738,-2.4906],
    'Xizang':
[0.0313,-0.0012,-0.0434,-0.1042,-0.1976,-0.3101,-0.3970,-0.4598,-0.5424,-0.
7186,-1.1458,-1.8529,-2.3344,-2.4991,-2.6303],
    'Xinjiang':
[0.1454,0.1443,0.1415,0.1334,0.0958,-0.0065,-0.1602,-0.2861,-0.3557,-0.4015
,-0.4654,-0.5697,-0.6484,-0.6822,-0.6773],
    'Yunnan':
[0.1140,0.1087,0.1028,0.0926,0.0618,-0.0131,-0.1266,-0.2283,-0.2968,-0.3408
,-0.3834,-0.4497,-0.5222,-0.5836,-0.6173],
    'Zhejiang':
[-0.0720,-0.0987,-0.1451,-0.2374,-0.3810,-0.4681,-0.4688,-0.5098,-0.6340,-0
.7586,-0.8751,-1.0245,-1.2828,-1.6207,-2.0926],
    'Chongqing':
[0.0386,0.0246,0.0046,-0.0251,-0.0744,-0.1444,-0.2172,-0.2833,-0.3594,-0.48
36,-0.7238,-1.0690,-1.3178,-1.4323,-1.5326]
}
# Convert to DataFrame
df = pd.DataFrame(data).set_index('year')

# Prepare data for plotting
years = df.index.unique()
box_data = [df.loc[year].values.flatten() for year in years]

# Set figure parameters
plt.figure(figsize=(8, 5))
plt.boxplot(box_data,
            positions=np.arange(len(years)),  # Ensure correct correspondence
with years
            patch_artist=True,
            showfliers=False,  # Do not display outliers
            boxprops=dict(facecolor='none', color='black'),  # Set box color
            whiskerprops=dict(color='black'),  # Set whisker color
            capprops=dict(color='black'),  # Set cap color
            medianprops=dict(color='black'))  # Set median line color
```

```
# Add labels and title
plt.xticks(np.arange(len(years)), years, rotation=45, fontsize=16,
fontname='Times New Roman')
plt.yticks(fontsize=16, fontname='Times New Roman')
plt.xlabel('Year', fontsize=16, fontname='Times New Roman')
plt.ylabel('Value Distribution', fontsize=16, fontname='Times New Roman')
plt.title('Pollutant Emissions per Unit GDP', fontsize=16, fontname='Times New
Roman')

# Add auxiliary line
plt.axhline(y=0, color='black', linestyle='--', linewidth=1)

# Adjust layout
plt.tight_layout()
plt.show()
```