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Spatio-temporal Heterogeneity in the Performance of Rural Revitalization in Chifeng City of China: Based on a Range-wide EBM-GML Model

Jiajing Li¹, Jianing Li², Pei Zhang^{1*}

¹School of Architecture, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055, China

²Inner Mongolia Student Aid Management Centre, Hohhot, Inner Mongolia, 010000, China

ABSTRACT

To solve the problems of rural revitalization performance research, a quantitative model of non-oriented range-wide EBM (Epsilon-Based Measure)-GML (Global-Malmquist) based on VRS (Variable Returns to Scale) conditions including non-desired outputs is constructed. A comprehensive spatio-temporal heterogeneity research index system of rural revitalization performance is also constructed. Taking the typical rural in Chifeng City as an example, the panel data from 2016-2020 are selected for empirical analysis, the conclusions and countermeasures are suggested as follows: 1) In general, the rural revitalization performance of Chifeng City increases significantly during the five-year period, with significant spatio-temporal heterogeneity. The overall analysis shows that the overall performance value of rural revitalization in Chifeng City is 0.683 from 2016 to 2020. The highest performance value is 1 and the lowest performance value is 0.389. The performance growth rate increases year by year, with an average annual growth rate of 4.46%. 2) From 2016 to 2020, the GML index of rural revitalization performance in Chifeng City is 1.174, showing an increasing trend. Based on the range of change of GML index, Chifeng City can be classified into three types: Continuous improvement, fluctuating improvement and fluctuating decline. 3) Niujiayingzi, Guandongche, Zhaidamu, and Qiangangtai rural have the highest degree of technological progress.

Keywords: Rural revitalization; Performance; EBM model; GML index; Spatio and temporal heterogeneity; Chifeng City

*CORRESPONDING AUTHOR:

Pei Zhang, School of Architecture, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, 710055, China; Email: zhangpei@xauat.edu.cn

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1. Introduction

Since the rural revitalization strategy is proposed, rural development has received wide attention and rural revitalization has become a research hotspot^[1]. The implementation of a rural revitalization strategy will definitely inject a strong impetus into the development of rural China^[2]. The performance assessment of rural revitalization provides valuable guidance, a standard system and social momentum for achieving the goals of rural revitalization planning^[3]. Currently, it is a critical period for the implementation of the rural revitalization strategy^[4]. To further promote the strategic planning of rural revitalization, we should solve realistic problems, make up for the shortcomings of people's livelihood, and strengthen incentives to continuously improve the assessment system^[5].

Therefore, this paper takes a problem-oriented approach, constructs a spatio-temporal heterogeneity research index system of rural revitalization performance, and builds a range-wide EBM-GML mathematical model. Select 12 typical rural of Chifeng City as research objects to understand the development of rural revitalization in different regions and assess the regional imbalance problems in the implementation of rural revitalization, which is very important for assessing the rural performance of other regions.

2. Literature review

The literature review is conducted in terms of rural revitalization and rural revitalization performance study by using Citespace to analyze the keyword co-occurrence network of related literature from 2002-2021.

2.1 Rural revitalization

(1) Theoretical research. In addition to policy revitalization and institutional revitalization, international rural revitalization research hotspots involve sociology, economics, urban and rural planning, geography, ecology and other multidisciplinary fields,

including talent revitalization, cultural revitalization and organizational revitalization. De Janvry A proposed that organizational revitalization should make policy maximize^[6]. Korsching P established a rural cultural revitalization management system^[7]. Hilary Tovey and Carr P J proposed a talent revitalization framework to guide rural construction^[8,9]. National studies are mainly in the fields of urban and rural planning, geography, and architecture, including paths and strategies for cultural revitalization, ecological revitalization, and industrial revitalization. Huang Juan et al. explored German rural planning and inspired rural revitalization in China^[10]. Zhang J. interpreted the "maintain and update" in rural cultural revitalization^[11]. Luo Zhendong et al. pointed out the path of rural cultural revitalization in the era of mobile Internet^[12]. Fan Lingyun et al. proposed an ecological planning strategy for rural revitalization^[13]. Chen Qianhu and Zhao Yi et al. proposed a high-quality revitalization path for rural industries^[14,15].

(2) Practice research. Most international practices for rural revitalization are focused on industrial revitalization and ecological revitalization. Kawate T and Irwin E G discussed different types of rural industries and categorized them for planning^[16,17]. Nonaka A summarized the practice and history of rural ecological revitalization^[18]. Li Z introduced rural planning and development^[19]. National practices for rural revitalization are mostly focused on rural construction planning. Zhang Rulin et al. explored the practice of rural revitalization planning in urban suburban areas^[20]. Gala Xiaojun et al. explored rural construction planning under the implementation orientation of rural revitalization strategy^[21].

2.2 Research on the performance of rural revitalization

International research on the performance of rural revitalization has gradually become research hotspots in multiple fields such as ecology and environment, economics, geography and anthropology along with the development of modern science in the West. Scholars mostly adopt quantitative analysis methods such as DEA (data envelopment analysis), system

analysis model, and data analysis model. Hodge I used the DEA model to assess typical rural [22]. Nemes G proposed an integrated and non-integrated system analysis model of rural revitalization [23]. María-Angeles Díez et al. added the application of rural revitalization data analysis models in performance assessment [24]. In contrast, national rural revitalization performance research start late, and although the overall number of research results show a trend of increasing year by year, they are mostly theoretical exploration based on their own disciplinary backgrounds, and interdisciplinary cross-sectional research is weak. The overall research is at the stage of theoretical system construction, and the practical application is slightly insufficient. Scholars mostly adopt qualitative analysis methods such as screening analysis, cluster analysis, hierarchical analysis, and principal component analysis, and the research perspectives are mainly focused on rural party organization, cultural governance, and rural tourism. Ji, C. Q. established a rural organization revitalization performance system [25]. Ma Xuejun and Wang Fujiang et al. established a rural cultural revitalization performance system [26,27]. Yuan Chen et al. established a rural tourism revitalization performance system [28]. Zhang Q and Yang Xue construct a performance evaluation index system for rural revitalization in China [29,30].

In summary, scholars of national and international have made some achievements in the study of rural revitalization performance using different research methods and from different perspectives, which enrich the connotation and theoretical methods of rural revitalization. It is of reference significance for the comprehensive study of rural revitalization performance.

2.3 Problems of national and international research

Through national and international studies, it is found that there are still some problems in the research on the performance of rural revitalization by national and international scholars. 1) Research objects. Usually, performance research is from one as-

pect, such as rural tourism performance, rural party organization performance, rural cultural governance performance, etc. There is a lack of holistic and systematic research on rural revitalization performance. 2) Research methods and model selection. Most of the research methods adopt principal component analysis and hierarchical analysis, which are assigned by experts, and the analysis results are more subjective and lack objectivity. The model mostly adopts the traditional DEA model, which has the disadvantages of not considering the non-desired output, limiting the radial measurement, poor precision and poor interpretation. 3) Construction of indicator system. The literature review reveals that the index system of national performance research is not theoretically based on national policies, and is mostly constructed according to the five aspects of the strategic objectives of rural revitalization or according to the *Strategic Plan for Rural Revitalization (2018-2022)* with few far-sightedness and scientificity. Meanwhile, input indicators and output indicators are selected with few ranges and small numbers; only hard indicators of quantitative description are considered, and soft indicators of qualitative description are ignored; only desired outputs such as economic development are considered, and non-desired outputs such as destruction and demolition are ignored. 4) Data selection. The data are usually cross-sectional data without considering time series, which cannot reflect the dynamic changes in rural revitalization performance over time. These shortcomings lead to the inability to assess the overall rural revitalization systematically, comprehensively and dynamically.

3. Realistic problems and contributions of this paper

3.1 Realistic problems

Through field research, the real problems are as follows:

(1) Fractured cultural inheritance and insufficient preservation awareness in the rural. The key to rural as another type of cultural heritage is its liveliness, that is to say, it is still alive and has the possibility

of continuation. However, rural culture faces the dilemma of fractured inheritance, and the phenomenon of “hollowing out” of cultural development is extremely serious. The problem of destruction and demolition of historical and cultural heritage is serious. There is a lack of revitalization and utilization of historical and cultural heritage, an insufficient manifestation of humanistic characteristics, fewer supporting resources for rural cultural construction, and fewer cultural theme activities.

(2) The construction of rural talent is poor, and cadres are not competent enough. First of all, the number of rural leaders and cadres, technicians and basic managers is insufficient, and the construction of a talent team needs to be improved. The number of party members in the rural is small, and the percentage of young party members is low. Secondly, the cadres’ ability is insufficient. Localities take various ways to organize rural cadres to visit and study in advanced areas, but cadres touch less on professional skills such as project selection, implementation and support, resulting in a lack of relevant project management experience and fear of appraisal and accountability for work mistakes.

(3) The level of industrial construction in rural is seriously different. Rural industrial revitalization in general presents differentiation. Different degrees of local policy inclination lead to different levels of rural industrial construction in each region. The industrial models are different, and there is a large gap in the momentum of the integration of agriculture and travel. The lack of integrated industrial chains leads to insufficient construction of the overall industrial chain for regional rural revitalization, making it difficult to bridge the realistic gap and form a synergized industrial model.

(4) Lack of linkage in rural revitalization and different management levels. The distribution characteristics and linkage features of the rural intensify the differentiation of the regional rural, and the overall rural revitalization of the region is not strong enough and the management level is different. The distribution pattern of large dispersion and small agglomeration and the graded development trend

makes it difficult to break multiple realistic barriers and form a unified and linked management model in rural revitalization in the face of natural and authority boundaries by natural landscape boundaries and regional jurisdictions.

3.2 Contribution of this paper

In order to solve the problems of rural revitalization performance research, this paper constructs a comprehensive index system for the study of spatio-temporal heterogeneity of rural revitalization performance and builds a range-wide EBM-GML mathematical model, which can comprehensively, objectively and accurately assess the dynamic implementation performance of rural revitalization. The contributions are as follows: 1) The index system is farsightedness and scientific. The literature review reveals that the index system of national performance research is not theoretically based on national policies, and is mostly constructed according to the five aspects of the strategic objectives of rural revitalization or according to the *Strategic Plan for Rural Revitalization (2018-2022)*, while the index system of this study is theoretically based on the latest national policies, which is more farsighted and scientific. The spatio-temporal heterogeneity research index system of rural revitalization performance, which contains 13 primary indicators, 20 secondary indicators and 36 tertiary indicators, is constructed based on the principles of systematicity, comprehensiveness, scientificity, operability and coordination. It strives to measure the overall dynamic implementation performance of rural revitalization in a comprehensive and multi-perspective way. 2) Innovate research methods. A non-oriented range-wide EBM-GML model based on VRS conditions and containing non-desired outputs is constructed. It contains both radial and non-radial directional distance functions, which can be projected to the strongly effective production frontier surface. Consider the non-desired output, and thus the study of rural revitalization performance is more comprehensive, objective, scientific and precise. Meanwhile, combined with the global reference GML index, it can reflect the impact of time change

on rural revitalization performance. 3) Dynamic data selection. The panel data from 2016-2020 are selected by considering the time series comprehensively to realize the dynamic measurement of rural revitalization performance.

4. Method: Model construction

4.1 EBM model

The reason why the EBM model is used in this paper instead of traditional DEA is that the advantages of the EBM model over traditional DEA are: 1) EBM model considers non-desired output, which makes the indicator system more comprehensive, while DEA does not consider non-desired output and the indicator system is not comprehensive enough. 2) The EBM model includes both radial and non-radial projections, which is optimal and most effective. While the traditional DEA selection is limited to radial measures^[31], this radial projection to the effective frontier surface is not optimal or most effective, and all inputs or outputs of the non-effective decision unit must be reduced or enlarged according to the same proportion before they become relatively effective^[32]. 3) The EBM model is more explanatory and more accurate than DEA after adding the second-order interaction term. The EBM model includes both radial and non-radial directional distance functions as shown in Equation (1).

$$\begin{aligned} \rho^* &= \min \theta - \varepsilon_x \sum_{i=1}^m \frac{w_i^- s_i^-}{x_{ij_0}} \\ \text{s. t. } &\sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{ij_0}, i = 1, \dots, m \\ &\sum_{j=1}^n y_{ej} \lambda_j \geq y_{ej_0}, e = 1, \dots, p \\ &\sum_{j=1}^n \lambda_j = 1 \\ &\lambda_j \geq 0, s_i^- \geq 0 \end{aligned} \tag{1}$$

ρ^* denotes the efficiency value of the EBM model with variable returns to scale. $0 \leq \rho^* \leq 1$. θ is the radial parameter. w_i^- is the value of the i importance

of the input, $\sum_{i=1}^m w_i^- = 1$. s_i^- is the slack variable for the type i input. x_{ij_0} is the type i input of the j_0 decision unit, with a total of m inputs. y_{ej_0} is the type e output of the j_0 decision unit, with a total of p outputs. λ is the degree of importance of the reference decision unit. ε_x is the combined parameter of the radial θ and non-radial slack variables, equal to 0 is equivalent to the radial model and equal to 1 is equivalent to the SBM model.

Since non-desired outputs such as ineffective preservation, ineffective management, and social assistance are involved, it is also considered that both input and output indicators can be projected radial or non-radial. For this reason, Equation (1) is extended to construct an undirected EBM model based on the VRS condition with non-desired outputs included. This is shown in Equation (2). The model includes non-desired outputs, and also includes proportional and slack projections, which can be projected onto the strong effective frontier surface, that is to say the optimal production frontier surface, thus making the performance of rural revitalization more comprehensive, scientific and accurate.

$$\begin{aligned} E(x_{j_0}, y_{j_0}, z_{j_0}) &= \rho^* \\ &= \min \frac{\theta - \varepsilon_x \sum_{i=1}^m \frac{w_i^- s_i^-}{x_{ij_0}}}{\varphi - \tau + \varepsilon_y \sum_{e=1}^p \frac{w_e^+ s_e^+}{y_{ej_0}} + \varepsilon_z \sum_{u=1}^q \frac{w_u^- s_u^-}{z_{uj_0}}} \\ \text{s. t. } &\sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{ij_0}, i = 1, \dots, m \\ &\sum_{j=1}^n y_{ej} \lambda_j - s_e^+ = \varphi y_{ej_0}, e = 1, \dots, p \\ &\sum_{j=1}^n z_{uj} \lambda_j + s_u^- = \tau z_{uj_0}, u = 1, \dots, q \\ &\sum_{j=1}^n \lambda_j = 1 \\ &\lambda_j \geq 0, s_i^- s_e^+, s_u^- \geq 0 \end{aligned} \tag{2}$$

where E is the directional distance function under the VRS condition, and z_{uj_0} is the type u non-desired output of the j_0 decision unit. w_e^+ is the importance

of the type e desired output. s_e^+ is the type e desired output slack variable. w_u^- is the importance of the type u non-desired output. s_u^- is the type u non-desired output slack variable.

4.2 GML index

The ML (Malmquist) index solves this problem. However, the ML index suffers from the problem of no feasible solution under VRS conditions. For this reason, an overall reference Malmquist index, the GML index method is used [41]. It uses the sum of all periods as the reference set. That is, the reference set common to all periods is:

$$S^g = S^1 \cup S^2 \cup \dots \cup S^p = \{(x_j^1, y_j^1)\} \cup \{(x_j^2, y_j^2)\} \cup \dots \cup \{(x_j^p, y_j^p)\}$$

Since the same frontier is referenced for each period, a single Malmquist Index is also calculated.

$$M_g(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t) = \frac{E^g(x^{t+1}, y^{t+1}, b^{t+1})}{E^g(x^t, y^t, b^t)}$$

Although the two adjacent periods refer to the same overall frontier in the calculation of the Malmquist Index, the calculation of changes in assessed values still uses the respective frontiers.

$$EC = \frac{E^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{E^t(x^t, y^t, b^t)}$$

The closeness of frontier t+1 to the overall frontier can be expressed as $\frac{E^g(x^{t+1}, y^{t+1}, b^{t+1})}{E^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}$ to indicate that a larger value indicates that the frontier t+1 is closer to the overall frontier. The degree of proximity of frontier t to the overall frontier, can be expressed as $\frac{E^g(x^t, y^t, b^t)}{E^t(x^t, y^t, b^t)}$ to indicate the closeness of frontier t to the overall frontier. The variation of frontier t+1 compared to frontier t can be expressed as the ratio of two ratios.

$$TC_g = \frac{E^g(x^{t+1}, y^{t+1}, b^{t+1}) / E^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{E^g(x^t, y^t, b^t) / E^t(x^t, y^t, b^t)}$$

The GML index can be decomposed into efficiency changes and technical changes.

$$M_g(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t) = \frac{E^g(x^{t+1}, y^{t+1}, b^{t+1})}{E^g(x^t, y^t, b^t)} \cdot \frac{E^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{E^t(x^t, y^t, b^t)} \cdot \left(\frac{E^g(x^{t+1}, y^{t+1}, b^{t+1})}{E^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \cdot \frac{E^t(x^t, y^t, b^t)}{E^g(x^t, y^t, b^t)} \right) = EC \times TC_g$$

Since the assessed decision unit is definitely included in the overall reference set, the overall reference Malmquist index. That is to say, the GML index does not have the problem of no feasible solution under VRS conditions. Since the reference in each period is the common overall frontier, the GML index possesses transferability and can be multiplied cumulatively.

4.3 Range-wide EBM-GML model

The non-oriented EBM model based on the VRS condition containing non-desired output is combined with the GML index to construct the non-oriented region-wide EBM-GML model based on the VRS condition containing non-desired output, as shown in Equation (3).

$$E_b^t(x_{jo}^t, y_{jo}^t, z_{jo}^t) = \min \frac{\theta - \varepsilon_x \sum_{i=1}^T \sum_{i=1}^m \frac{w_i^- s_i^-}{x_{ijo}}}{\varphi - \tau + \varepsilon_y \sum_{e=1}^T \sum_{e=1}^p \frac{w_e^+ s_e^+}{y_{ejo}} + \varepsilon_z \sum_{u=1}^T \sum_{u=1}^q \frac{w_u^- s_u^-}{z_{ujo}}}$$

$$s.t. \sum_{i=1}^T \sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{ijo}, i = 1, \dots, m$$

$$\sum_{i=1}^T \sum_{j=1}^n y_{ej} \lambda_j - s_e^+ = \varphi y_{ejo}, e = 1, \dots, p$$

$$\sum_{i=1}^T \sum_{j=1}^n z_{uj} \lambda_j + s_u^- = \tau z_{ujo}, u = 1, \dots, q \tag{3}$$

$$\sum_{i=1}^T \sum_{j=1}^n \lambda_j = 1$$

$$\lambda_j \geq 0, s_i^-, s_e^+, s_u^- \geq 0$$

4.4 Model test

Model testing is the research and testing process to determine the correctness, validity, and credibility of a model. In this study, four types of tests are combined and the results are as follows: 1) Model structure suitability test: Consistent magnitudes, equations meet extreme conditions, and appropriate model bounds. 2) Model behavior suitability test: Parameter sensitivity and structure sensitivity are high. 3) Model structure consistency test with the actual

system: Appearance test, parameter meanings and their values are consistent. 4) Model behavior and actual system consistency test: Model behavior can reproduce the reference model, extreme behavior of the model, and simulation under extreme conditions are consistent.

5. Empirical analysis

5.1 Typical experience of rural revitalization in Chifeng City

The demonstration significance of typical experience of rural revitalization in Chifeng is focused on “organization construction as a lever to promote comprehensive rural revitalization”. In recent years, in response to the outstanding contradictions and problems of “small scale of operation, scattered production patterns and low level of industrial structure” that have long existed in rural development, Chifeng National Rural Revitalization Demonstration Zone based on the functional positioning of ecological cultured area, has started with the construction of collective economic organizations at the town and rural levels led by party building, and enhanced the level of collective economic coordination. It has completed the restructuring of the organizational system, the restructuring of the land use structure of rural, the restructuring of the industrial chain led by the union of talents, and the stimulation of the potential value of cultural resources and ecological advantage resources. The potential value of the project has been enhanced. Project funds have been integrated and connected to cultivate green and healthy vibrant rural around the key work and weak links such as industrial development and cultural construction. Great progress has been made in the construction of demonstration projects, and a practical path with exemplary significance for the comprehensive promotion of rural revitalization has been initially formed.

(1) Organizational construction. The construction of rural basic organizations has been strengthened. 87 weak and lax rural party organizations have been rectified continuously and incorporated rural affairs openness and democratic management into the or-

ganization construction. The first clerks fully played an important role in the party building and rural revitalization promotion, and the pilot task of building a national rural governance system in Yuanbaoshan District and Ningcheng County has been completed. The construction of innovative demonstration of rural-level deliberation and consultation has been carried out.

(2) Industrial development. Expanded the multiple functions of agriculture, tapped the multiple values of the rural, and continuously improved the quality and efficiency of rural modern agriculture. It has created modern agricultural parks, increased the organization of farmers’ participation in industrial operations, and promoted the integration of rural industrial projects with science practice and study education.

(3) Ecological preservation. It has promoted the green development of agriculture and rural areas. The carbon sink capacity of rural forest resources increased by 150,000 tons, and the forest coverage rate reached over 40.7%. The strategic white temporary greening of 883 hectares has been implemented. A national ecological civilization construction demonstration area and “green water and green mountains is the silver mountain” practice innovation base has been created. The construction of national agricultural green development pioneer areas in Hongshan District and Songshan District has been promoted.

(4) Cultural prosperity. The cultural resources of the rural have been fully explored. The Chinese Farmers’ Harvest Festival Chifeng celebration, Chifeng Farmers’ Art Festival, other festive folklore activities and mass cultural activities have been widely carried out. Cultural excavation and preservation have been promoted, organized rural material and intangible cultural heritage resources, and produced series of rural culture documentaries.

(5) Integration of rural and urban areas. Strengthened the supply of basic public services in rural areas, strengthened the construction of rural medical and health systems, staffed rural doctor positions, and enhanced rural medical and health services. Enhanced the integrated development of compulso-

ry education in urban and rural areas, and steadily increased the coverage of high-quality teaching resources in rural areas. Multi-functional and multi-purpose service facility complexes have been built. The social assistance system has been improved to effectively protect the basic livelihood of farmers in difficulty.

(6) Support measures. The construction of rural help team has been strengthened. Innovated rural support model: First, implemented rural collective economic support measures, increased collective income through collective economic support, utilized one hundred idle farm buildings. The special action of helping rural with weak collective economy has been strengthened. Second, increased the support measures for agricultural insurance and agricultural finance, increased the number of insurance varieties and the number of agricultural futures varieties, improved the coverage rate of agricultural insurance, and expanded the amount of equity financing for agriculture-related enterprises.

(7) Supervision and inspection. Implemented the *Regulations on Supervision and Inspection of Chifeng City Rural*, strengthened the assessment and accountability of responsible units and responsible persons around the issue of rural revitalization. Comprehensive analysis, periodic dispatch and departmental coordination mechanisms have been established to carry out periodic inspection and periodic evaluation, which has enhanced the supervision and inspection capacity of the rural.

5.2 Research object

The research object is 12 typical rural of Chifeng City. They are representative because they are national rural revitalization demonstrated rural, national "one rural, one product" demonstrated rural, Chinese beautiful leisure rural, national key rural of tourism, and national forest rural in 2019. They are: Guandongche Rural, Chaidamu Rural, Tongbu Rural, Qiangangtai Rural, Zhazhaiyingzi Rural, Guduhe Rural, Dongnanyingzi Rural, Qianjin Rural, Niujiayingzi Rural, Wanan Rural, Hada Rural, Dongtala Rural.

The rural of Chifeng shows a significant spatio distribution with large dispersion and small agglomeration characteristics (see **Figure 1**). At the macro level, Firstly, the areas in the south of Chifeng are the main agglomeration areas, with high density values and large area distribution characteristics. Secondly, rural is more distributed in the north of the city, forming secondary agglomerations. At the micro level, rural are mostly concentrated in Hongshan District, Songshan District and Ningcheng County.

5.3 Indicator System

Theoretical basis for the construction of the indicator system

(1) Policy theoretical basis

The policy theoretical basis of the study is *The Law of the People's Republic of China on the Promotion of Rural Revitalization*, which was adopted by the Standing Committee of the 13th National People's Congress of the People's Republic of China in 2021. It stipulates that the focus should be on rural industrial development, talent support, cultural prosperity, ecological preservation, organizational construction, urban-rural integration, support measures and supervision and inspection, and the comprehensive implementation of the rural revitalization strategy^[33], which is urgently needed to promote comprehensive upgrading of agriculture, comprehensive progress of rural areas and comprehensive development of farmers, and accelerate the modernization of agriculture and rural areas. At the same time, it actively carries out activities to promote the revitalization of rural industries, talents, culture, ecology and organization, and to promote the development of urban-rural integration.

(2) Economic theoretical basis

The economic theoretical basis of the study is the Cobb-Douglas production function^[34]. It is a production function created by the American mathematician C.W. Cobb and economist Paul H. Douglas when they jointly explored the relationship between inputs and outputs. In this paper, according to the Cobb-Douglas production function, funds, work-



Figure 1. Geographic information and spatio distribution of rural areas in Chifeng City.

force, material resources, and technological progress are considered comprehensively in the construction of the index system.

Indicator Construction

There are some problems in the construction of the previous indicator system. For example, input indicators and output indicators are selected with few regions and small quantities; only hard indicators with quantitative descriptions are considered, and soft indicators with qualitative descriptions are ignored; only desired outputs such as industrial development are considered, and non-desired outputs

such as poor preservation and social assistance are ignored.

In order to solve the real problems in the construction of indicators, this paper, based on the policy and economic theories and combined with the national rural revitalization strategy, constructs a spatio-temporal heterogeneity research indicator system of rural revitalization performance, which contains 13 primary indicators, 20 secondary indicators and 36 tertiary indicators, aiming to measure the rural revitalization performance comprehensive and with multi-perspective, and the finally formed index system (see **Table 1**).

Table 1. Research index system of spatio and temporal heterogeneity of rural revitalization performance.

Indicators	Primary Indicators	Secondary indicators	Tertiary indicators
Input Indicators	Fund	Agricultural support funds	Financial funds (billion yuan)
			Social funds (billion yuan)
	Workforce	Talent Construction	Specialized funds (billion yuan)
			Number of technical and basic management staff (number)
	Material resources	Land	Number of leaders (number)
			Area of agricultural land (thousand hectares)
	Industry Development	Industrial Park Industrialization	Land utilization rate (%)
			Number of modern agricultural parks (number)
	Cultural Prosperity	Cultural Heritage Preservation	Cultural Heritage Preservation
			Number of agricultural cultural heritage (number)
Cultural Practices			
Number of intangible cultural heritage (number)			
Ecological Preservation	Ecological restoration	Number of cultural and sports activities (times)	
		Area of wetland restoration (thousand hectares)	
Desired Output Indicators	Organization construction	Basic organizations	Area of grassland restoration area (thousand hectares)
			Greening degree
	Urban-rural integration	Public Education	Forest cover (%)
			Ruralrs' satisfaction rate with the openness of rural affairs and democratic management (%)
	Support measures	Agricultural Insurance	Ruralrs' satisfaction rate with the rural committee (%)
			Economic Organizations
Non-desired output indicators	Supervision and Inspection	Inspection and evaluation	Number of professional cooperative economic organizations (number)
			Proportion of junior high school going on to high school (%)
	Inadequate preservation	Destruction and demolition	Medical health care
			Medical Prevalence Rate (%)
	Ineffective management	Appraisal and Accountability	Social Security
			Medical insurance participation rate (%)
	Social Assistance	Social assistance workers	Endowment insurance participation rate (%)
			Agricultural Finance
			Number of insurance varieties (number)
			Coverage rate of agricultural insurance (%)
			Amount of equity financing for agriculture-related enterprises (billion yuan)
			Number of agricultural product futures varieties (number)
			Number of inspection (times)
			Number of periodic evaluate (times)
			Number of natural resources destroyed (number)
			Number of old buildings and ancient dwellings demolished (number)
			Number of responsible units and responsible persons punished (number)
			Number of rural residents with minimum living standards (10,000 people)
			Number of rural special hardship people in centralized care (10,000 people)
			Number of rural special hardship people in scattered care (10,000 people)

(1) Input indicators. According to the Cobb-Douglas production function, the inputs of the fund, workforce, material and technical progress are considered comprehensively, among which technical progress is a soft indicator, which is more difficult to be assessed quantitatively and cannot be put into the index system, so the GML index can measure the degree of contribution of technical progress to the overall performance. In terms of funds, the funds for supporting agriculture are selected, and the financial funds, social funds and specialized funds can reflect the funds for supporting agriculture; in terms of workforce, the talent construction is selected^[35], and the number of technicians, basic managers and the number of leaders can reflect the talent construction; in terms of material resources, the land is selected, and the number of agricultural land and land utilization rate can reflect the land situation^[36].

(2) Desired output indicators. They are constructed according to several aspects: Industrial development, cultural prosperity, ecological preservation, organization construction, urban-rural integration, support measures, supervision and inspection. In terms of the industry, the industrial parks, industrialized operation are selected, and the number of industrial parks and the participation rate of farmers in industrialized operation can reflect industrial development; in terms of the culture, the cultural heritage preservation and cultural practice are selected, and the number of agricultural cultural heritage and intangible cultural heritage can reflect cultural heritage preservation, the number of cultural and sports activities and festive folklore activities can reflect cultural practice; in terms of the ecology, the ecological restoration and greening degree can be measured, the area of wetland restoration and grassland restoration can reflect the ecological restoration, and the forest coverage rate can reflect the greening degree; in terms of the organization, the basic organizations and economic organizations can be measured, the satisfaction rate of ruralers with the openness and democratic management of rural affairs and the satisfaction rate of ruralers with the rural committee can reflect the basic organizations and the number of

professional cooperative economic organizations can reflect the economic organizations; in terms of the urban-rural integration, the public education, medical and medical health care, and social security can be selected, in terms of urban-rural integration, public education, medical health care and social security are selected. Public education is characterized by the rate of junior high school to senior high school; medical health care is characterized by the prevalence rate of medical care; social security is characterized by the number of service institutions and service social organizations, medical insurance participation rate and endowment insurance participation rate^[37]. In terms of support, agricultural insurance and agricultural finance are selected, the number of insurance varieties and agricultural insurance coverage rate can reflect agricultural insurance; the amount of equity financing for agriculture-related enterprises and the number of agricultural futures varieties can reflect agricultural finance. In terms of supervision, the number of inspections and periodic evaluations can reflect the inspection and evaluation.

(3) Non-desired output indicators. They are constructed from three aspects: ineffective preservation, ineffective management, and social assistance. In terms of ineffective preservation, the number of destruction and demolition of natural resources, the number of demolition of old buildings and ancient dwellings can reflect the destruction and demolition situation; in terms of ineffective management, the number of responsible units and responsible persons punished can reflect the appraisal and accountability; in terms of social assistance, the number of social assistance workers can reflect the social assistance, the number of rural residents with minimum living standards, number of rural special hardship people in centralized and number of rural special hardship people in scattered care can reflect the social assistance^[38].

Indicator Test

The possible redundancy of the tertiary indicators in the rural revitalization performance assessment index system has been tested. The redundancy analysis method based on the combination of qualitative and

quantitative correlation is adopted. After considering the calculation speed and accuracy, the Apriori algorithm is used for qualitative correlation analysis after discretizing the evaluation index values, and then the least squares method and the great uncorrelated method are used for further quantitative correlation analysis, and the results show that there is no obvious correlation among the tertiary indicators. Therefore, the indicator system is not redundant.

5.4 Data collection and processing

(1) Data sources. The data related to the spatio and temporal heterogeneity of rural revitalization performance research index system are obtained from the field research of the subject group from January 2019 to January 2023, interviews with farmers, interviews with relevant departments (Chifeng Rural Social and Economic Survey Team of National Bureau of Statistics, Chifeng Bureau of Statistics, Chifeng Bureau of Agriculture and Animal Husbandry) and relevant internal books. Since the data involve five years of local policies, management, financial audits, participation of multiple interest subjects and other more sensitive information, they are internal information and cannot be made public.

(2) Type of data. The data type is numerical.

(3) Data collection. Three data collection methods are used in the study. 1) Field research method: To conduct a comprehensive investigation of the current situation of rural revitalization in Chifeng City through field visits, field surveys, household interviews and departmental discussions, and to collect a large amount of data information such as relevant photos and videos of the current situation and conduct in-depth analysis. 2) Computer-aided method: Using basic geographic information and related image information as spatio database, based on the GIS platform, we collect and organize geographic information and spatio data, and carry out a series of spatio analysis and processing in order to extract relevant knowledge information, Such as topography, spatio distribution and other digital image information. 3) Internal information access method: local information data collection through internal books,

documents and other materials.

(4) Data processing. Based on the characteristics of the data, for the non-completely missing data, the parabolic interpolation method is used to obtain the specific missing data. For the completely missing data, the average value of the item in other rural in the corresponding year is used as the indicator data of the rural that year.

5.5 Analysis of the results

The spatio-temporal heterogeneity of rural revitalization performance in Chifeng City from 2016 to 2020 is studied using the above-mentioned range-wide EBM-GML model, and the results are obtained by mathematical modeling using Matlab software (see **Table 2**, **Figure 2**, **Figure 3**, **Table 3**, **Figure 4**, and **Figure 5**).

Combined with **Table 2** and **Figure 3**, the overall analysis shows that the overall performance value of rural revitalization in Chifeng is 0.683 from 2016 to 2020, and the performance has increased significantly over the five-year period. Among them, the rate of increase is relatively stable in 2017, and the rate of increase is faster in 2018, 2019, and 2020. The average annual growth rate of performance is 4.46%.

Combined with **Table 2** and **Figure 4**, analyzed by regions, the top four rural of Chifeng city in terms of rural revitalization performance from 2016 to 2020 are Dongnanyingzi rural, Guduhe rural, Qianjin rural, and Wanan rural; the middle four rural are Zhazhaiyingzi rural, Guandongche rural, Dongtala rural, and Niujiayingzi rural; the last four rural are Chaidamu rural, Qiangangtai rural, Tongbu rural, and Hada rural. It can be seen that the performance of rural revitalization in the southern part of Chifeng City is generally better than in other regions.

Analyzed the dynamic trend of spatio and temporal evolution, from 2016 to 2020, the rural revitalization performance of Guduhe and Dongnanyingzi rural increased significantly; Qianjin and Wanan rural fluctuated and increased; Zhazhaiyingzi, Niujiayingzi and Dongtala rural steadily increased; Guandongche, Chaidamu and Tongbu rural are relatively stable; Qiangangtai rural decreased faster and Hada

Table 2. Performance rank of rural revitalization in Chifeng City.

Rural Name	2016	2017	2018	2019	2020	Average Value	Rank
Guandongche	0.748	0.727	0.768	0.768	0.791	0.760	6
Chaidamu	0.485	0.522	0.523	0.563	0.561	0.531	9
Tongbu	0.529	0.442	0.473	0.464	0.518	0.485	11
Qiangangtai	0.588	0.554	0.500	0.474	0.506	0.524	10
Zhazhaiyingzi	0.702	0.696	0.742	0.829	0.874	0.769	5
Guduhe	0.699	0.754	0.896	0.991	1.000	0.868	2
Dongnanyingzi	0.735	0.833	0.865	1.000	1.000	0.887	1
Qianjin	0.781	0.831	0.804	0.917	0.974	0.861	3
Niujiayingzi	0.495	0.516	0.535	0.600	0.626	0.554	8
Wanan	0.791	0.773	0.869	0.840	1.000	0.855	4
Hada	0.428	0.413	0.388	0.411	0.405	0.409	12
Dongtala	0.629	0.646	0.650	0.708	0.814	0.690	7
Average Value	0.634	0.642	0.667	0.713	0.755	0.682	

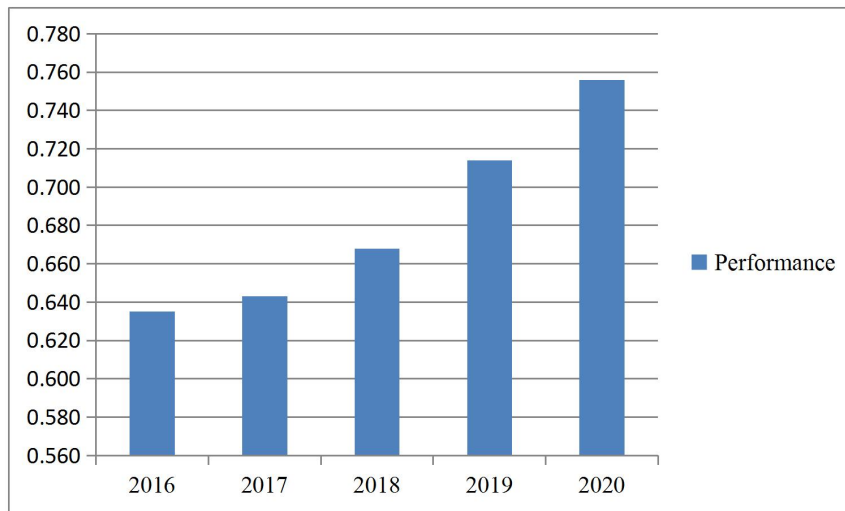


Figure 2. Performance of rural revitalization of Chifeng City by year.

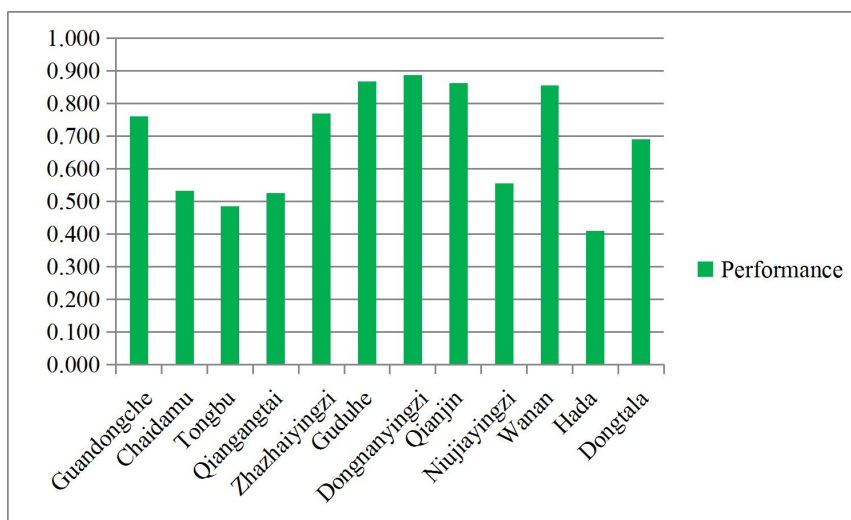


Figure 3. Performance of rural revitalization of Chifeng City by region.

rural decreased slightly.

In terms of performance gap analysis, the highest performance value of 1 in 2016-2020 occurs in Dongnanyingzi rural in 2019, Dongnanyingzi, Wanan and Guduhe rural in 2020. The lowest performance value of 0.389 occurs in Hada rural in 2018. The highest performance occurs in Wanan rural and the lowest performance occurs in Hada rural in 2016; the highest performance occurs in Dongnanyingzi rural and the lowest occurs in Hada rural in 2017; the highest performance occurs in Guduhe rural and the lowest occurs in Hada rural in 2018; the highest performance occurs in Dongnanyingzi rural and the lowest occurs in Hada rural in 2019; the highest performance occurs in Guduhe, Dongnanyingzi and

Wanan rural and the lowest occurs in Hada rural in 2020. It can be seen that the rural with the best performance in the five-year period are concentrated in Dongnanyingzi, Guduhe, and Wanan rural. The performance of Hada rural is consistently poor. Meanwhile, it can be seen that the gap between the highest and lowest performance areas in the same year from 2016 to 2020 shows an increasing trend year by year.

Combined with **Table 3** and **Figure 5**, the overall analysis shows that the GML index of rural revitalization performance in Chifeng is 1.174 in 2016-2020, showing an increasing trend. Among them, the growth rate is faster in 2016-2017, 2017-2018 and 2018-2019, and the growth rate decreases slightly in 2019-2020.

Table 3. GML index of rural revitalization performance of Chifeng City.

Rural Name	2016-2017	2017-2018	2018-2019	2019-2020	2016-2020	Rank
Guduhe	0.972	1.056	1.001	1.030	1.057	9
Tongbu	1.077	1.003	1.077	0.997	1.156	8
Dongtala	0.835	1.071	0.982	1.117	0.978	10
Hada	0.943	0.904	0.949	1.068	0.861	12
Qianjin	0.992	1.067	1.118	1.054	1.244	7
Niujiayingzi	1.080	1.189	1.107	1.010	1.431	1
Guandongche	1.134	1.039	1.157	1.001	1.361	2
Dongnanyingzi	1.065	0.969	1.141	1.063	1.248	6
Qiangangtai	1.043	1.038	1.122	1.044	1.264	4
Wanan	0.978	1.125	0.967	1.191	1.263	5
Zhazhaiyingzi	0.966	0.941	1.060	0.986	0.947	11
Chaidamu	1.026	1.007	1.090	1.151	1.292	3
Average Value	1.009	1.034	1.064	1.059	1.175	

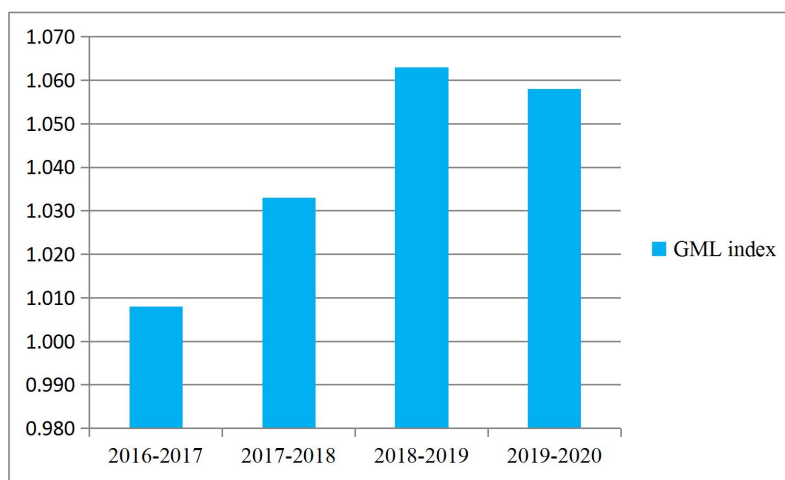


Figure 4. GML index of rural revitalization performance by year of Chifeng City.

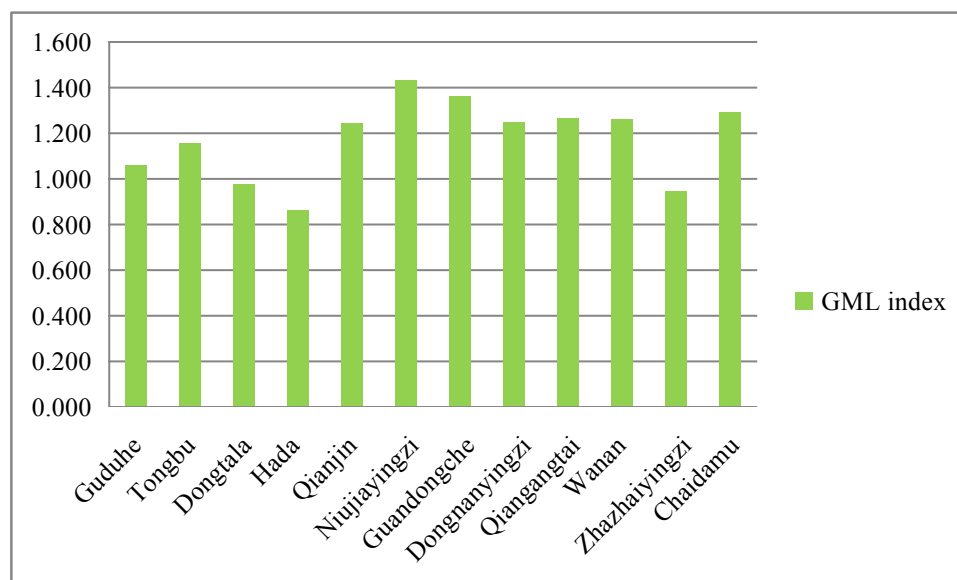


Figure 5. GML index of rural revitalization performance by region of Chifeng City.

Combined with **Table 3** and **Figure 5**, analyzed by region, the top four rural in the Rural Revitalization Performance of Chifeng GML Index from 2016 to 2020 are Niujiayingzi, Guandongche, Chaiyamu, and Qiangangtai Rural; the rural in the middle are Wanan, Dongnanyingzi, Qianjin, and Tongbu Rural; and the last rural are Guduhe, Dongtala, Zhazhaiyingzi, and Hada Rural.

From 2016 to 2020, the rural with rising performance are Guduhe, Tombu, Qianjin, Niujiayingzi, Guandongche, Southeast Yingszi, Qiangangtai, Wanan, and Chaidamu, of which: Qiangangtai and Chaidamu are rising rapidly and Rank in the top 4 overall; the rural with falling performance are Dongtala, Hada, and Zhazhaiyingzi.

From the analysis of spatio-temporal heterogeneity, based on the range of changes in GML index, Chifeng can be divided into three types: Continuous improvement type, fluctuating improvement type, and fluctuating decline type. Niujiayingzi, Guandongche, Qiangangtai, and Chaidamu rural belong to the continuous improvement type; Guduhe, Tongbu, Qianjin, Dongnanyingzi, and Wanan rural belong to the fluctuating improvement type; Dongtala, Hada, and Zhazhaiyinzi rural belong to the fluctuating decline type.

From the analysis of technological progress, the main contribution to the rising performance of rural

revitalization in the southern of Chifeng City comes from technological progress. Among them, Niujiayingzi, Guandongche, Zhaidamu, and Qiangangtai rural have the highest degree of technological progress, followed by Wanan, Guduhe and Qianjin rural.

6. Conclusions and countermeasure suggestions

By using the range-wide EBM-GML model, the performance of rural revitalization in Chifeng City from 2016 to 2020 is assessed, the implementation of rural revitalization in Chifeng and countermeasures are suggested as follows:

1) The overall performance is improving year by year, while the parts showing high in the southern and northern regions, low in the eastern and western regions.

After analyzing the data of specific indicators and assessment results, it is found that the dynamic assessment performance values of most rural are steadily increasing, no matter the overall rural revitalization by year and by region. This is due to the effective implementation of the national rural revitalization policy of rural in Chifeng.

However, due to the different resource advantages, location advantages, development stages of rural revitalization and degree of spatio gathering of

different rural, the performance of rural revitalization shows a high trend in the southern and northern region, and a low trend in the eastern and western regions. Since the southern region has a better resource advantage, obvious location advantage, and earlier development stage of rural revitalization, as well as being a high-density gathering area (both in terms of the degree of spatio gathering and quantity of spatio gathering, it exceeds other regions), it is generally better than other regions in terms of rural revitalization performance. In order to solve the problem of regional differences, efforts should be made to achieve the linkage development of rural revitalization. On the one hand, the southern and northern regions should continue to consolidate the achievements, update the rural revitalization model, and enhance the radiation and driving effect on the eastern and western regions. On the other hand, the eastern and western regions should learn more from the advanced experience of the southern and northern regions to continuously improve the quality and efficiency of rural revitalization.

2) The extreme difference in assessment increases year by year, showing the Matthew effect.

The analysis of the assessment results shows that the gap between the rural with the highest and lowest assessment values in the same year increases year by year, showing the Matthew effect. This indicates that there is an imbalance in regional performance assessment and a growing gap between assessment values. Therefore, it is necessary to strengthen policy orientation, integrate planning and promotion. On the one hand, strengthen the overall preservation. Integrate the revitalization of rural in Chifeng into the development of rural in eastern Inner Mongolia, so as to make the scope of revitalization broader and deeper. At the same time, reduce non-desired outputs such as destruction and demolition to achieve the goal of strong preservation. On the other hand, strengthen the overall management. At the management level, the management efficiency of rural in Chifeng is improved by reforming the management mode of rural revitalization. At the same time, reduce non-de-

sired outputs such as appraisal and accountability to achieve the goal of effective management.

3) Strengthen technical empowerment and revitalize rural scientifically.

From the assessment results, it is found that the global reference GML index shows an upward trend, indicating that the dynamic assessment performance value is gradually improving. The overall rural revitalization technology progress is significant. Among them: Niujiayingzi, Guandongche, Chaidamu and Qiangangtai rural have made obvious technical progress in rural revitalization. Technology is the premise of efficiency and a powerful tool to improve rural performance. Therefore, in rural revitalization, it is necessary to strengthen technological empowerment, continuously learn advanced technological concepts, and transform technological achievements in time to realize scientific revitalization of rural.

Although this paper has achieved some innovative results, there are inevitably shortcomings and limitations in the research of this paper due to objective factors. For example, the literature is limited, the summary of the existing research is insufficient, and the data collection is inadequate. It needs to be further improved in the future.

Author Contributions

Conceptualization, J.L. (Jiajing Li) and J.L. (Jianing Li); methodology, J.L. (Jiajing Li); software, J.L. (Jianing Li); validation, J.L. (Jianing Li); formal analysis, J.L. (Jiajing Li) and J.L. (Jianing Li); investigation, J.L. (Jiajing Li); resources, P.Z.; data curation, J.L. (Jiajing Li) and J.L. (Jianing Li); writing-original draft preparation, J.L. (Jiajing Li); writing-review and editing, J.L. (Jianing Li); visualization, J.L. (Jiajing Li) and J.L. (Jianing Li); supervision, P.Z.; project administration, P.Z.; funding acquisition, P.Z.

Conflict of Interest

There is no conflict of interest.

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