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GREY RELATIONAL ANALYSIS OF R&D INPUT AND OUTPUT IN CHINA BASED ON A PANEL DATA

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ABSTRACT

Science and technology innovation is a crucial factor that affecting the comprehensive competitiveness and sustainable development of a country. And it is mainly derived from the guiding the R & D activities, including three types of activities, namely basic research, applied research and experimental development. According to the panel data of R & D input and output of China's regional R & D institutions, the Grey Relational Analysis method is used to analyze the relationship between R & D input and output of China's regional R & D institutions, and to obtain the important influencing factor of current regional R & D activity output in China. The research shows that the number of scientific papers produced areis greatly affected by the number of R & D personnel inputs, and the number of published scientific and technical works is generally more related to the investment, patents are more relevant to the three types of R & D activities, the formation of national or industry standards is significantly related to the funding and personnel input of basic research activities. Based on the results, the suggestions for improving R & D output and optimizing input resource structure are put forward.

KEYWORDS: *Science and Technology Management, R & D Input and Output, Panel Data, Grey Relational Analysis*

INTRODUCTION

Research and Development (R & D) refers to systematic and creative activities in the field of science and technology to increase the total amount of knowledge and use this knowledge to create new applications. R & D activities include basic research, application research, and experimental development [1]. R & D activity is an important source of technological innovation in a country or a region, and an important reflection of the strength of science and innovation. R & D institution is the most important subject in an of R & D activity. The efficiency of R & D activities by R & D institutions directly affects regional and national technological innovation level. China's increasing emphasis on scientific and technological innovation has led to an increase in the total amount of R & D personnel and funding, and the gap with the countries with strong innovation capabilities has gradually narrowed. However, in terms of R & D output levels and resource utilization efficiency, the gap between China and other countries is still large, as reflected in the poor quality of China's R & D output and the few original innovations [2]. The reason is that the R & D input resource allocation structure is not satisfactory. The specific performance is: from the perspective of resource input structure, the proportion of basic research and applied research is insufficient. From the perspective of the geographical distribution of resource input, R & D funds are concentrated in coastal areas. Based on the above background, analyzing the relationship between input and output in R & D activities can provide a reference for how to improve output under limited resources, and it is of great significance to improve the research and development efficiency of R & D institutions in China and to promote regional technological innovation. The analysis of R & D input and output at home and abroad mostly focuses on performance analysis, and the research fields are mostly concentrated on in enterprises and industries [3–6]. There are few studies on the relationship between R & D input and output of R & D institutions in terms of resource allocation structure. Therefore, the research direction of this paper has a certain novelty and innovation.

As an important method of sequence relationship analysis, Grey Relational Analysis (GRA) has been successfully applied in many fields such as management, economy, society, industry, agriculture, transportation, and chemical industry [7-9]. However, these studies usually rely on sequence data or cross-sectional data, and there are few studies that investigating the relationship between panel data. As a combination of cross-section data and time-series data, panel data can overcome the multi-co linearity of time series analysis and provide the richer information. At present, the research on the GRA of panel data is still rare. Zhang Ke [10] proposed to extend the absolute relational degree of grey, make up for the blank application of GRA theory in panel data. Afterwards, some scholars made further improvements to the 3D GRA model for panel data analysis. For example, Wang Hui, Wei Yong [11] defined the two special categories of nearness relational degree and the similarity relational degree based on the panel data, which further promotes the development of the 3D GRA theory. Jiang Shiquan, Liu Sifeng, Liu Zhongxia, Xie Naiming [12] constructed a relational degree model of grey panel data for the case where the panel data type is a general grey number. The theory of 3D GRA is still in the process of continuous improvement and development. Based on theNo matter in theory or in algorithms, there is no perfect universal calculation method. In order to make it better apply to practical problems, the application background and data should be analyzed first, and then based on this analysis;, the appropriate GRA model can be selected.

Based on the relevant indicator characteristics of input and output of R & D activities of the R & D institutions, this paper selects the 3D GRA model to investigate relationships between R & D input and output indicators based on the panel data of 2013-2017 China Science and Technology Statistical Year book. The GRA aims to provide recommendations regarding for R & D resources investment to in Chinese R & D institutions.

The first part of the article explains the important role of R & D activities and the problems faced by China in R & D input and output. The second part gives the theoretical methods for research. The third part uses the GRA method to study the relationship between R & D input and output based on China's panel data, and the results are analyzed in depth. Finally, based on the results summary is made.

3d GRA Method

Sequence relationship analysis typically uses correlation tests in statistics. However, statistical methods require a high number of data samples, and the association of the two sequences is often difficult to proceed with pass rigorous statistical tests. In order to overcome the above shortcomings, this paper uses the GRA method which has no need for special requirements on the number of samples and statistical laws to analyze the degree of correlation between various factors by describing the geometric relationship between data sequences. Panel data is a collection of observations at different points in time by multiple indicators of different research objects. It has both empirical information of space and time, that reflecting the development level and development dynamics of all objects under the corresponding indicators. Therefore, using panel data has more general information than using cross-section data or time series data. Different from the traditional single-index data sequence, the panel data needs to consider three dimensions when calculating the relevance degree, which is generally the index dimension, the object dimension and the time dimension. The GRA models aiming at these three dimensions are inter-indicator GRA model, inter-object GRA model and inter-time GRA model. Based on the GRA method of panel data proposed by Liu Zhen[13], Cui Lizhi and Liu Sifeng[14], according to the characteristics of the data, the inter-indicator 3D GRA model is used to analyze the relationship between R & D input indicators and output indicators. In addition, this paper splits the panel data into multiple time series data, calculates the grey comprehensive relational degree between R & D input index and output index in each region, and makes a comparative analysis of the relationship between R & D input and output in each region. Because the grey comprehensive relational analysis model only disassembles the panel data into simple time series data or cross-section data, and the calculation process is consistent with the 3D grey comprehensive relational degree. This paper only introduces the 3D GRA method, and the related definitions are as follows:

Definition 1[15]: Let X_i be a system factor whose behaviour value is a_ij at the point (i,j) in the two-dimensional space, where i≤M,j≤N, M and Nare constants, A_i=(a_ij)_(M×N), and A_i is called the behaviour matrix of the system factor X_i.

Definition 2[15]: Set the system behaviour matrixX=(a_ij)_(M×N), D,D_1 is the matrix operator, if

$$X^0 = XD = (a_{ij}d)_{M\times N} = (a_{ij} - a_{i1})_{M\times N} \qquad (1)$$

Where i=1,2,⋯,M;j=1,2,⋯,N.

Then, D is the starting edge zeroing operator of the behaviour matrix, and X^0 is the starting edge zeroing image of X. If

$$X_1 = D_1X = (d_1a_{ij})_{M\times N} = (\frac{a_{ij}}{a_{i1}})_{M\times N} \qquad (2)$$

Where a_i1≠0;i=1,2,⋯,M;j=1,2,⋯,N.

Then, D_1 is the initial value operator of the behaviour matrix, and X_1 is the initialized image of X.

The above operator is the most basic initialization operator, where D can move the panel data parallelly, and D_1 can eliminate the effects of dimension.

Definition 3[15]: Let the two system behaviour matrices X_p=(a_(i,j))_(M×N) and X_q=(b_(i,j))_(M×N) then the three-dimensional grey absolute relational degree is

$$\varepsilon_{pq} = \frac{1+|s_p|+|s_q|}{1+|s_p|+|s_q|+|s_p-s_q|} \qquad (3)$$

Where |s_p |, |s_q | and |s_p-s_q | represents the volume of the top curved cylinder enclosed by the two initialized zeroed cambers and the coordinate plane, and the volume of the top curved cylinder enclosed by the two curved cambers, respectively, and the calculation formula is:

$$s = \int_1^M \int_1^N X^0\, dxdy \qquad (4)$$

Definition 4[15]: Let the two system behaviour matrices X_p=(a_(i,j))_(M×N), X_q=(b_(i,j))_(M×N), where a_(1,j)≠0,b_(1,j)≠0,j=1,2,⋯,N. X_p^' and X_q^' are the initialized images of X_p and X_q, and the three-dimensional absolute relational degree between X_p^' and X_q^' is called the three-dimensional relative relational degree between X_p and X_q, which is recorded as r_pq.

Definition 5[15]: Let two system behaviour matrices X_p=(a_(i,j))_(M×N), X_q=(b_(i,j))_(M×N) be the same type matrix, where a_(1,j) ≠ 0,b_(1,j) ≠ 0,j = 1,2,⋯,N.ε_pqis the three-dimensional absolute relational degree, and r_pq is the three-dimensional relative relational degree. Then

$$\rho_{pq} = \theta\varepsilon_{pq} + (1 - \theta)r_{pq} \quad (5)$$

Is the three-dimensional comprehensive relational degree

Between X_p and X_q, where θ∈ [0,1].

Based on the above Five Definitions, the Calculation Process of the 3D GRA Method is as Follows:

Step 1: Initialize the panel data using the initialization operator in Definition 2. The purpose of panel data initialization is to eliminate the influence of gap on the quantitative level, and reset the corresponding cambers to the same starting edge for calculation and analysis.

Step 2: Calculate the volume of the top curved cylinder enclosed by the starting edge zeroing cambers and the coordinate plane by using the formula (4).

Step 3: Calculate the three-dimensional absolute relational degree, relative relational degree and comprehensive relational degree according to definitions 3-5.

Empirical Analysis on the Relationship between R & D Input and Output in China

Based on the statistical data of national and regional research institutions, this paper analyzes the relationship between R & D input and output of R & D institutions in China by using the GRA method. And on this basis, the main input indicators affecting R & D output across the country and regions are determined and compared.

Data Source and Indicator Selection

According to UNESCO, Research and Development (R & D) is a systematic and creative work, which aims to increase the total amount of knowledge including human, cultural and social aspects, and use this knowledge to develop new applications. Generally, R & D includes three types of activities: basic research, applied research, and experimental development. Basic research refers to theoretical work that does not consider any role at the application level, but only to obtain a better understanding of the phenomenon. Applied research refers to creative research that was conducted to extend the theory to practical applications. Experimental development refers to the systematic work for of further using of the knowledge obtained from basic research and applied research to promote the output and improvement of new products, new processes and other related services.

The output of different R & D activities may not be the same. In order to examine the impact of the resource input of the three types of R & D activities on the output, the study will select relevant input-output indicators from the three types of R & D activities and use 3D GRA method to explore the relationship between various input-output indicators.

R & D output mainly refers to the direct results caused by R & D activities, including a series of scientific and technological innovation achievements such as patents and papers. The research uses R & D results as a first-level indicator of output, and also uses specific scientific and technological innovation achievements, that is, the number of papers, books, patents and industry standards as a secondary output indicators.

R & D input refers to the resources used in various R & D activities. Generally, it can be measured from the input of people, finance and material. Since the input of materials can be measured with the funds invested in goods, the research will take the expenditure of equipment and instruments required for R & D activities as the entry point for investigating the level of materials. Therefore, the first-level indicators of input mainly include personnel investment and financial investment, and the second-level indicators are related to personnel that involved in various R & D activities and the expenditure of each R & D activity. In addition, the because full-time equivalent is an important international standard for comparing R & D manpower input and can be different from the manpower input of various R & D activities;, it is added to the personnel input indicator. Relevant input and output indicators are selected as shown in Table 1.

Based on the selection of the above-mentioned input-output indicators and that combined with the statistical data of China Statistical Yearbook of Science and Technology (2013–2017) [16], this paper relies on panel data of R & D activities of scientific research institutions in 31 provincial administrative regions in China.

Table 1: R & D Input and Output Indicators of R & D Institutions

Primary Indicators	Secondary Indicators	Unit	Code
R & D personnel input	Full-time Equivalent of R & D Personnel	man-year	X_1
	Basic Research Persons	Person	X_2
	Applied Research Persons	Person	X_3
	Experimental Development Researchers	Person	X_4
R & D expenditure input	Basic Research Expenditure	10,000 Yuan	X_5
	Applied Research Expenditure	10,000 Yuan	X_6
	Experimental Development Expenditure	10,000 Yuan	X_7
	Equipment Expenditure	10,000 Yuan	X_8
R & D output	Scientific Papers Issued	Piece	Y_1
	Publication on S&T	Kind	Y_2
	Patents Application	Piece	Y_3
	Number of National and Industrial Standard	Item	Y_4

GRA of R & D Input and Output Based On Panel Data

Taking the R & D output data as the reference sequence, the 3D grey comprehensive relational degree is calculated by using Python programming, and the correlation matrix of each input factor and output result is shown in table 2.

In order, to more intuitively if we see there is a relationship between the input factors and the output results, this paper presents a line graph showing the results of GRA (Figure 1).

Figure 1 shows as depicted in Figure 1, the input factors affecting the number of scientific papers issued (Y1) are ordered as: X4>X3>X1>X2>X8>X6>X7>X5; the order of input factors affecting the publication on S&T (Y2) is: X7>X2>X8>X6>X5>X3>X4>X1; The order of input factors affecting the number of patents application (Y3) areis: X2>X4>X3>X5>X7>X8>X6>X1; input factors affecting the number of national and industrial standard (Y4) are: X5>X2>X7>X8>X6>X3>X4>X1.

It can be seen from the calculation results that the number of scientific papers produced is highly correlated with the number of people invested in the three types of R & D activities， so scientific papers issued areis greatly affected by the number of persons of various R & D activities, and the impact of funding is small, indicating that the

R & D funds invested have not fully played their role. In general, the degree of relevance between the number of published scientific and technical works and investment funds is greater, but the number of basic researchers is also one of its significant factors. In addition, the number of patent applications has a strong correlation with the researchers of three types of R & D activities, and the correlation with the number of basic researchers is the highest largest. At last, we can see that the number of the national and industrial standard is significantly related to the funding and personnel input of basic research activities.

The greater the degree of grey correlation between input and output indicators the bigger the role of input factors in promoting output and can be called as promoting factors. However, if the degree of grey correlation is too small, it indicates that the input indicator does not fully exert its influence on the output indicator, which is called as the constrained factor. In order to improve the performance of R & D activities, we should steadily increase the input level of each promoting factor, and analyze the constrained factor to determine whether the excessive investment causes waste of resources, so as to achieve the same or more output with a less input.

Table 2: Extended Grey Relational Matrix of Each Input Factor and Output Result

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Y_1	0.812	0.746	0.893	0.906	0.533	0.568	0.559	0.569
Y_2	0.558	0.722	0.583	0.566	0.639	0.697	0.724	0.703
Y_3	0.640	0.957	0.692	0.778	0.686	0.655	0.674	0.663
Y_4	0.533	0.681	0.539	0.534	0.729	0.620	0.636	0.623

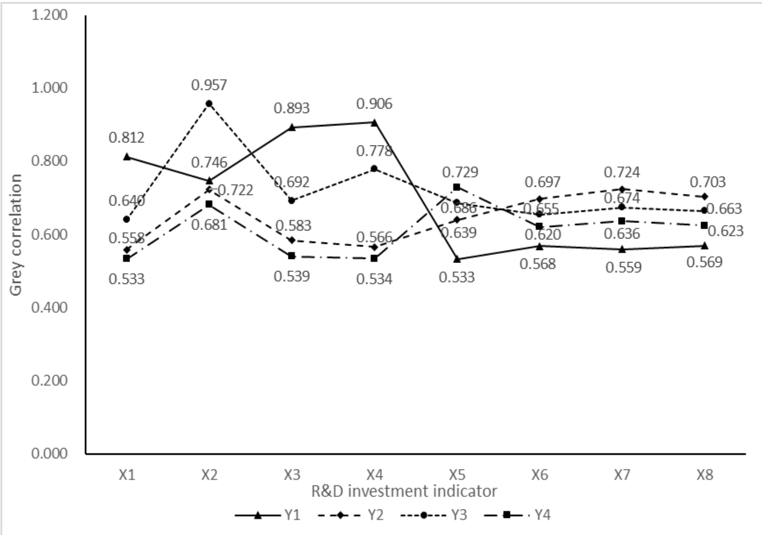

Figure 1: 3D Comprehensive Grey Relational Degree Line Chart of R & D Input and Output.

Comparative Analysis of R & D Input-Output Relationships in Different Regions Based on the Time Series Data

According to different regions The panel data is divided into time series data according to different regions, and the grey comprehensive correlation degree between various R & D input factors and output results in each region in the past five years is calculated separately. Due to space limitation, only the analysis results of Beijing (Table 3) are listed as Example.

As shown in the Table 4, this paper summarizes the input factors for the maximum and minimum grey relational degree of R & D output indicators for different regions.

It can be seen from Table 4 that although the relational degrees between R & D input and output are not the same in different regions, the biggest correlation factor of the four outputs in most regions is the R & D personnel input indicators, and the factors with the low gray correlation are the funding input indicators. Specifically, among the 31 regions, the largest influencing factor for all R & D output in 11 regions is personnel input, and the biggest influencing factor for the three R & D output in 12 regions is personnel input. Accordingly, the minimum influencing factor for R & D output in 15 of the 31 regions is funding. These data shows that R & D institutions in most parts of China are under the circumstances that a research talent determines the scientific research results. Therefore, in the relevant regions, the number of R & D personnel should be increased, the R & D expenditure level should be adjusted and controlled, and R & D resources should be allocated reasonably to improve the performance level of R & D activities. In addition, we also found that in areas such as Tibet where the economic base is weak and the investment in research funds is low, the gray correlation between R & D expenditure input and output is large, and the correlation between personnel input and output is small. For these regions, relevant government agencies can promote the output of R & D results by increasing the level of funding invested. Through the above comparative analysis, the promoting factors and constrained factors of R & D output in various regions are clarified, and targeted recommendations can be made for the development of science and technology innovation in various regions.

Table 3: Grey Relational Matrix of Various Input Factors and Output Results in Beijing

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Y_1	0.945	0.883	0.755	0.641	0.609	0.650	0.618	0.621
Y_2	0.638	0.721	0.700	0.580	0.691	0.737	0.711	0.710
Y_3	0.759	0.863	0.703	0.573	0.712	0.717	0.732	0.733
Y_4	0.559	0.549	0.561	0.656	0.537	0.544	0.539	0.539

Table 4: Promoting Factors and Constrained Factors for Regional R & D Output

Region	Promoting Factors				Constrained Factors				Region	Promoting Factors				Constrained Factors			
	Y_1	Y_2	Y_3	Y_4	Y_1	Y_2	Y_3	Y_4		Y_1	Y_2	Y_3	Y_4	Y_1	Y_2	Y_3	Y_4
Beijing	X_1	X_6	X_2	X_4	X_5	X_4	X_4	X_5	Hubei	X_4	X_3	X_1	X_2	X_5	X_7	X_3	X_3
Tianjin	X_2	X_3	X_2	X_1	X_5	X_5	X_5	X_5	Hunan	X_1	X_3	X_2	X_7	X_8	X_8	X_8	X_5
Hebei	X_5	X_1	X_5	X_4	X_7	X_7	X_6	X_6	Guangdong	X_2	X_3	X_2	X_7	X_7	X_8	X_8	X_8
Shanxi	X_6	X_2	X_8	X_5	X_5	X_5	X_4	X_4	Guangxi	X_3	X_3	X_2	X_5	X_7	X_7	X_7	X_7
Inner Mongolia	X_2	X_5	X_2	X_2	X_3	X_3	X_3	X_3	Hainan	X_8	X_7	X_4	X_3	X_5	X_5	X_5	X_5
Liaoning	X_1	X_1	X_2	X_2	X_8	X_8	X_8	X_8	Chongqing	X_4	X_4	X_4	X_5	X_5	X_5	X_5	X_7
Jilin	X_4	X_4	X_2	X_4	X_5	X_5	X_4	X_5	Sichuan	X_3	X_2	X_3	X_2	X_8	X_8	X_2	X_8
Heilongjiang	X_1	X_1	X_3	X_3	X_7	X_7	X_5	X_7	Guizhou	X_1	X_6	X_3	X_8	X_6	X_7	X_6	X_7
Shanghai	X_4	X_3	X_2	X_6	X_7	X_7	X_8	X_8	Yunnan	X_3	X_3	X_2	X_8	X_5	X_5	X_3	X_5
Jiangsu	X_4	X_4	X_3	X_5	X_5	X_2	X_8	X_8	Tibet	X_1	X_5	X_7	X_4	X_2	X_4	X_4	X_2
Zhejiang	X_3	X_3	X_2	X_2	X_5	X_5	X_5	X_6	Shaanxi	X_4	X_2	X_3	X_4	X_6	X_6	X_4	X_6
Anhui	X_4	X_5	X_2	X_3	X_8	X_3	X_3	X_8	Gansu	X_3	X_7	X_2	X_3	X_5	X_3	X_3	X_5
Fujian	X_1	X_3	X_4	X_3	X_7	X_7	X_6	X_7	Qinghai	X_1	X_2	X_8	X_3	X_6	X_6	X_2	X_2
Jiangxi	X_3	X_6	X_2	X_5	X_8	X_8	X_4	X_4	Ningxia	X_3	X_2	X_7	X_4	X_4	X_4	X_6	X_6
Shandong	X_6	X_3	X_2	X_2	X_7	X_7	X_6	X_6	Xinjiang	X_4	X_4	X_2	X_2	X_6	X_6	X_4	X_4
Henan	X_1	X_1	X_3	X_2	X_5	X_5	X_5	X_7									

CONCLUSIONS

Scientific research statistical data is a solid foundation and important support for mastering the research status of the country and the region, formulating science and technology policies, and then preparing scientific and technological development plans. Making full use of the entire scientific research statistics, mining its hidden information, discovering the problems existing in the development of scientific and technological innovation and making the improvements is one of the important means to promote scientific and technological progress. Based on the panel data of 31 provincial-level administrative regions in the past five years, this paper analyzes the relationship between R & D input and output of R & D institutions in China. Through empirical analysis, we can know that the relationship between different inputs and different outputs is different, and the relationship between R & D inputs and outputs in different regions is also different.

As the core of scientific research, R & D activities can reflect the status of knowledge production and knowledge utilization of R & D institutions, and also can reflect the level of technological innovation development of regions and countries. Although China's R & D activities have grown over the years in terms of personnel, funding and output, there are still cases where the efficiency of resource allocation is not high enough and the output of each outcome is uneven. Based on the analysis results of this paper, relevant institutions should optimize the R & D resource allocation according to the actual requirements of national and regional technological innovation capability development, and to take advantage of the factors that promotes R & D output to improve the overall R & D level.

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