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Research on Evaluation of Scientific and Technological Innovation Capability of Beijing Based on Catastrophe Progression Theory

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***Abstract*—This paper uses the annual data from 2001 to 2015 of Beijing through catastrophe progression method to do the research on evaluation of scientific and technological innovation capability of Beijing based on catastrophe progression theory and the development of catastrophe system model. The results show that the innovation ability of science and technology in Beijing is generally on the rise, and this ability improves dramatically, stably and then greatly; each evaluation index level of scientific and technical innovation capability in Beijing differs in the enhancement of this capability. This paper illustrates that catastrophe progression theory has a certain scientificity and rationality in the evaluation of regional scientific and technical innovation capability.**

Keywords*—*scientific and technical innovation; catastrophe progression; catastrophe model; evaluation index

I. INTRODUCTION

The ability of scientific and technological innovation is not only the basis and booster of regional economic development but also the key factor of new regional competition advantages under the background of globalization. At present, domestic scholars on the scientific and technological innovation ability evaluation research has achieved fruitful results. For example, Tian Zhikang et al. (2008) proposed the evaluation method of national innovation ability based on BP neural network by the "European Innovation Scoreboard" index, as well as evaluated and compared China's scientific and technological innovation ability [1];Li Qian et al (2010) [2], Su Yi and Li Bozhou (2011) [3], and Li Jun et al (2012) [4] respectively utilized grey relational analysis, tournament, TOPSIS based on OWA, and other methods to conduct corresponding empirical analysis and evaluation of regional science and technology innovation ability. However, for these evaluation methods, there are some problems including complex calculation (such as the neural network method) and high degree of subjectivity of determining the weight (such as the analytic hierarchy process). In view of the above situation, this paper uses catastrophe progression theory to evaluate the scientific and technological innovation ability of Beijing in order to obtain valuable conclusions. The main characteristic of catastrophe progression theory is the application of the catastrophe fuzzy membership function to evaluate based on the hierarchy of the overall system evaluation goal. Catastrophe progression theory avoids the problem of serious subjectivity in determining weight, embodying the scientific and rationality of the evaluation to a certain extent, and its calculation is simple and accurate. Therefore, the application of catastrophe progression theory is of important theoretical value and practical significance to do the research on scientific and technical innovation capability of Beijing, development of its relevant evaluation index, and building of the scientific and technical innovation center with global influence in Beijing.

II. CATASTROPHE PROGRESSION THEORY AND THE EVALUATION STEPS

A. Catastrophe Progression Theory Literature

French mathematician Rene Thom illustrated catastrophe theory by topology, singularity, stability and other mathematical concepts in his book Structural Stability and Morphogenesis in 1972 [5]. Catastrophe theory provides a new perspective for people to understand the natural and social phenomena, which has aroused great concern from domestic scholars, and the theory has been widely used in many disciplines. For example, Li Yan et al. (2007) used catastrophe progression method to evaluate the health of regional ecosystems [6]; Wu Fengqing and Li Jianxia (2010) researched the evaluation of self-innovation capability of large and medium-sized industrial enterprises in China's 29 provinces on the basis of the catastrophe progression method, and put forward targeted Improving methods [7]; He Lianzhi Wei and Song Xiaoming (2013) applied the catastrophe progression method to carry on the comprehensive analysis of the industrial upgrading ability of the regional large and medium-sized high-tech enterprises [8]; based on catastrophe theory, Li Caihui et al. (2015) [9], Gao Yifan (2015) [10], Li Zheng et al (2017) [11] respectively conducted empirical research on urban low-carbon competitiveness, China's economic development, and science and technology evaluation methods.

B. Catastrophe Progression Evaluation Steps

(1) Building the catastrophe evaluation index system. According to the overall goal of system evaluation, the system is decomposed into several multi-level systems composed of several evaluation indexes and resolve these indexes step by step. The decomposition of evaluation indicators follows the quantifiable principle and these indicators are generally broken down into measurable sub-indicators. Control variables of the ordinary catastrophe system do not exceed four, so the corresponding level indicator decomposition should not exceed four.

(2) Determining the type of the catastrophe system. The most common types of the catastrophe system include fold catastrophe, cusp catastrophe, swallow tail and butterfly; the system model types, sate variables, control variables and potential functions are shown in Table 1.

(3) Deriving the normalization formula for comprehensive evaluation. Because the ranges of the system state variables and control variables are not consistent, it is necessary to limit the ranges of state variables and control variables in each catastrophe model from 0 to 1, ,which is normalization, and the normalization formula is a multidimensional fuzzy membership function (see Table 1). The values of x calculated by each control variable in the normalization formula take principle of average values or the “Minimax" criterion.

TABLE I. POTENTIAL FUNCTIONS AND NORMALIZATION FORMULAS ON CATASTROPHE PROGRESSION SYSTEM MODELS

Types of system models	The number of state variables	The number of control variables	Potential functions	Normalization formulas
Fold catastrophe	1	1	$f(x)=x^3+ax$	$x_a=a^{\frac{1}{2}}$
Cusp catastrophe	1	2	$f(x)=x^4+ax^2+bx$	$x_a=a^{\frac{1}{2}}, x_b=b^{\frac{1}{3}}$
Swallow tail catastrophe	1	3	$f(x)=\frac{1}{5}x^5+\frac{1}{3}ax^3+\frac{1}{2}bx^2+cx$	$x_a=a^{\frac{1}{2}}, x_b=b^{\frac{1}{3}}, x_c=c^{\frac{1}{4}}$
Butterfly catastrophe	1	4	$f(x)=\frac{1}{6}x^6+\frac{1}{4}ax^4+\frac{1}{3}bx^3+\frac{1}{2}cx^2+dx$	$x_a=a^{\frac{1}{2}}, x_b=b^{\frac{1}{3}}, x_c=c^{\frac{1}{4}}, x_d=d^{\frac{1}{5}}$

[a] Note: x is the state variable, f (x) the potential variable of the state variable x, and a, b, c, d are the control variables of the state variable x

III. EVALUATION OF SCIENTIFIC AND TECHNICAL INNOVATION CAPABILITY IN BEIJING

A. Development of Evaluation Index System

First, build the catastrophe evaluation index system. Synthesizing research literature at home and abroad, based on the scientific nature of the selection of indicators, the availability of data calculations and other principles. This paper builds the evaluation index system of scientific and technical innovation capability in Beijing.

B. Identification of Catastrophe System Models

According to catastrophe progression theory, catastrophe system models for each layer of indicators in the evaluation index system of Beijing science and technology innovation ability is given from bottom to top.

C. Source and Disposition of Data

According to the evaluation index system of science and technology innovation ability in Beijing, the data of this paper is the relevant annual data of Beijing science and technology innovation from 2001 to 2015. The basic data are from every year′ s "Beijing Statistics Yearbook", "China City Statistical Yearbook”, "China Statistical Information Collection" and "China Statistical Yearbook on Science and Technology"; some scientific and technological innovation index data need to be calculated or replaced.

To eliminate the impact of different dimensions of the original data, the original index data must be dimensionlessly standardized, and the formula is as follows:

$$y_i=\frac{x_i-x_{\min}}{x_{\max}-x_{\min}} \quad (1)$$

Where i = 1, 2, ..., n (n is the number of indicators)

D. Utilization of The Normalization Formula for Model Calculation

Taking factor level B3, factor level B1, factor level B8 and criterion level A4 for example, this paper respectively illustrates specific calculation process of fold, cusp, swallow tail and butterfly catastrophe models.

(1)Fold catastrophe model. There is the fold catastrophe model for index layer of local fiscal public budget expenditure growth rate C_5 directly delivered by factor level of policy environment B_3, then:

$$x_{B_3} = x_{C_5}^{\frac{1}{2}} \quad (2)$$

(2) Cusp catastrophe model. There is the cusp catastrophe model for index level of the scientific and technical personnel C_1 and R & D staff equivalent to full time equivalent C_2 decomposed by factor level of Innovation talent B1, then:

$$x_{B_1} = (x_{C_1}^{\frac{1}{2}} + x_{C_2}^{\frac{1}{3}})/2 \quad (3)$$

(3) Swallow tail catastrophe model. There is the swallow tail catastrophe model for index level of the ratio of total deposits and loans of financial institutions to regional GDP C_{12}, the ratio of the transaction volume of the securities market to the regional GDP C_{13}, and the proportion of premium income to regional GDP C_{14} decomposed by factor level of financial services B_8, then:

$$x_{B_8} = (x_{C_{12}}^{\frac{1}{2}} + x_{C_{13}}^{\frac{1}{3}} + x_{C_{14}}^{\frac{1}{4}})/3 \quad (4)$$

(4) Butterfly catastrophe model. There is the butterfly catastrophe model for factor level of technological achievements B_9, economic outputB_{10}, structural optimization B_{11}, and radiation lead B_{12} decomposed by criterion level innovation performance A_4, then:

$$x_{A_4} = (x_{B_9}^{\frac{1}{2}} + x_{B_{10}}^{\frac{1}{3}} + x_{B_{11}}^{\frac{1}{4}} + x_{B_{12}}^{\frac{1}{5}})/4 \quad (5)$$

According to the above steps and methods, the final evaluation of scientific and technological innovation capability results in Beijing from 2001 to 2015 can be figured out (see Table 2).

TABLE II. BEIJING 2001 ~ 2015 SCIENTIFIC AND TECHNOLOGICAL INNOVATION CAPACITY EVALUATION RESULTS

Year	Innovation resource	Innovation environment	Innovation service	Innovation performance	Scientific and technical innovation capability
2001	0.0000	0.3288	0.2283	0.3380	0.5466
2002	0.6824	0.6865	0.5940	0.7145	0.8803
2003	0.6928	0.7797	0.7004	0.7818	0.9049
2004	0.7771	0.8275	0.7254	0.7784	0.9236
2005	0.8487	0.8240	0.7385	0.8019	0.9356
2006	0.8944	0.8652	0.8175	0.8493	0.9543
2007	0.9240	0.9027	0.8390	0.8535	0.9634
2008	0.9264	0.8665	0.8735	0.8835	0.9645
2009	0.9350	0.8807	0.9073	0.8725	0.9686
2010	0.9393	0.8871	0.9375	0.8894	0.9727
2011	0.9570	0.9236	0.8200	0.8955	0.9705
2012	0.9765	0.8928	0.8640	0.9231	0.9748
2013	0.9803	0.8833	0.8910	0.9355	0.9770
2014	0.9871	0.6552	0.9189	0.9394	0.9572
2015	0.9872	0.9982	0.9726	0.9458	0.9937

IV. ANALYSIS OF EVALUATION RESULTS

On the whole, scientific and technical innovation capability of Beijing is mainly on the rise from 2001 to 2015, and the change of this capability has gone through three stages: from 2001 to 2003, in the stage of rapid increase (0.55-0.90), the dramatic changes in the innovative resource and ability led to the upgrading of scientific and technological innovation ability; from 2003 to 2014,scientific and technological innovation ability increased stably (0.90-0.96); from 2014 to 2015, the ability improved greatly due to great development of the innovation environment and ability boosted the scientific and technological innovation ability.

Specifically, (1) the innovation resources mainly focus on R & D personnel, R & D funds, the proportion of fiscal and technological expenditure, and other indicators; improvement of scientific and technological innovation ability has connection with increasing attention of Beijing to innovative elements like Innovative talent and funds in the scientific and technological innovation development. (2) The decline in the public budget expenditure and the number of books published per capita in the innovation environment has seriously affected the ability of scientific and technological innovation. On the guarantee of the scientific and technological innovation environment, in addition to the basic living environment, Beijing should create a favorable policy and culture environment. (3) Disorderly development exists in Beijing's innovative service capabilities. Supporting service for scientific and technical innovation should be well done by Beijing, including enhancement of information conditions and financial development. (4) Beijing needs to consolidate scientific research achievements, adjust the industrial structure and gain green development in the process of improving Innovation performance.

V. CONCLUSION

According to current problems, such as complicated calculation, seriously subjective weight determination in regional science, and technology innovation ability evaluation, based on catastrophe progression theory and the construction of the scientific and technological innovation capability evaluation catastrophe system model of Beijing, this paper conducts empirical research and analysis of scientific and technical innovation capability in Beijing, making use of relevant data from 2001 to 2015 in Beijing by catastrophe progression. The results show that the innovation ability of science and technology in Beijing is generally on the rise, and this ability improves dramatically, stably and then greatly; each criterion level of scientific and technical innovation capability in Beijing differs in the enhancement of this capability. The catastrophe system model not only comprehensively evaluates the scientific and technological innovation capability of Beijing, but also reflects the advantages and disadvantages of the capability from different criteria. This shows that catastrophe progression theory has a certain scientificity and rationality in the evaluation of regional scientific and technical innovation capability.

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