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Predicting the Number of Beijing Science and Technology Personnel Based on GM(1,N) Model

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Abstract

In this paper, based on the Science and Technology Statistics in Beijing Statistical Yearbook, grey theory is used to study the relationship among S&T (Science and Technology) activities personnel, R&D (research and development) personnel FTE (Full Time Equivalent), intramural expenditure for R&D and Patent Application Amount. According to the grey correlation coefficient, screening of grey GM(1,N) prediction variables, the grey prediction model is established. Meanwhile, time series model and GM(1,1) model are established for patent applications and R&D personnel equivalent FTE. By comparing the simulating results with the real data, the absolute relative error of prediction models is less than 10%. The results of the prediction model are tested. In order to improve the prediction accuracy, the mean values of the predicted values of the two models are brought into the GM(1,N) model to predict the number of scientific and technical personnel in Beijing during 2015-2025. Forecast results show that the number of science and technology personnel in Beijing will grow with exponential growth trend in the next ten years, which has a certain reference value for predicting the science and technology activities and formulating the policy in Beijing.

Keywords

Grey Relational Analysis, GM(1,N) Model, Time Series, Science and Technology

1. Introduction

The functions of Beijing in the Beijing-Tianjin-Hebei integrations region are the national political center and cultural center, international exchange center, science and technology innovation center. While science and

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technology innovation is the core of a country, a regional competitiveness, national strategy advocates strengthening science and technology innovation ability. Beijing, as the capital of China and international metropolis, its science and technology innovation plays a role of "leader". Scientific and technological innovation capability is an important guarantee to optimize the allocation of scientific and technological resources, improve the efficiency of investment in science and technology, and promote the economic development of technology. Many scholars have made a lot of research on the impact of science and technology investment on economic output. Wei and Li (2005) using the econometric methods to study the impact of R&D input intensity, scientific and technical personnel, the per capita possession of a number of factors on the export of high-tech products [1].

Guo and Wang (2011) use science and technology statistics by SPSS statistical software to study the relationship between the number of scientific and technological activities and high-tech products exports [2]. Scientific and technical personnel is the fundamental factor to promote scientific and technological progress and technological innovation; science and technology personnel's strength reflects the local science and technology strength and innovation ability [3]. The patent application, scientific and technological activities and R&D expenses and other variables are used to estimate the specific knowledge production function of Henan Province by Luo (2015) [4]. Fu (2012) involved in scientific and technological activities of personnel in the comparison of the transformation of R&D institutions and foreign R&D institutions in Beijing, and pointed out that the study of scientific and technical personnel assessment should be strengthened [5].

The number of patent application is the barometer of economic and social development. In this paper, based on the Science and Technology Statistics in Beijing Statistical Yearbook, grey theory is used to study the relationship among S&T activities personnel, R&D personnel FTE, intramural expenditure for R&D and Patent Application Amount. And time series and GM(1,1) model are used to predict the number of patent applications and research and development (R&D) staff equivalent to full-time equivalents for years of 2015-2025, and then GM(1,N) model is used to predict the number of municipal scientific and technological activities for the next decade.

2. Grey Correlation Analysis

Grey correlation analysis is a systematic and effective analysis method in the grey system theory. The quantitative description of the development trend of the system is based on the correlation between factors [6].

The specific process of grey correlation analysis is:

1) Determine the analysis sequence

A reference sequence to determine the behavior characteristics of the system is:

$$Y_0 = \left\{ Y_0(k) \middle| k = 1, 2, \cdots, n \right\}. \tag{1}$$

A comparative sequence to influence the behavior characteristics of the system is:

$$Y_i = \left\{ Y_i(k) \middle| k = 1, 2, \cdots, n \right\},\ i = 1, 2, \cdots, n. \tag{2}$$

2) Dimensionless variables

The sequence of the factors in the system of data may be due to the different dimension, not easy to be compared, or cannot get the correct conclusion, so in advanced dimensionless analysis of the grey correlation.

$$X_i(k) = \frac{Y_i(k)}{Y_i(1)},\ k = 1, 2, \cdots, n;\ i = 0, 1, 2, \cdots, n. \tag{3}$$

Resulting from the reference sequence of dimensionless sequence is as follows:

$$X_0 = \left\{ X_0(k) \middle| k = 1, 2, \cdots, n \right\}. \tag{4}$$

After the comparative sequence of dimensionless get sequence is as follows:

$$X_i = \left\{ X_i(k) \middle| k = 1, 2, \cdots, n \right\}; i = 1, 2, \cdots, n. \tag{5}$$

3) Grey correlation coefficient

Calculate grey correlation coefficient between reference sequence X_0 and compare sequence $X_1, X_2, \cdots, X_n$.

The calculation formula is as follows:

$$\xi_i(k)=\frac{\min\{|X_{0k}-X_{ik}|\}+\xi\max\{|X_{0k}-X_{ik}|\}}{|X_{0k}-X_{ik}|+\xi\max\{|X_{0k}-X_{ik}|\}}, i=1,2,\cdots,n \tag{6}$$

where, $\xi\in[0,1]$ is distinguishing coefficient, the smaller the coefficient, the greater the resolution. The general value is $\xi=0.5$.

4) Gray correlation degree

The grey correlation degree between the reference sequence Y_0 and the comparison sequence Y_i is calculated. Because the reference sequence and comparative sequence in the curve of the various points of the degree of correlation is not a value, but too scattered, so calculating the average of the various points in the curve, as the correlation degree of reference sequence and compare sequence. The formula is as follows:

$$r_i=\frac{1}{n}\sum\xi_i(k),\ k=1,2,\cdots,n;\ i=1,2,\cdots,n. \tag{7}$$

In the formula, r_i represents the grey correlation degree between the reference sequence Y_0 and the comparison sequence Y_i.

5) Correlation degree ranking

When $r_1>r_2$, it means the comparison sequence X_1 is much more similar than sequence X_2 for reference sequence *Y*.

In the Beijing statistical yearbook, according to the statistical data from 1996 to 2014, the grey theory is used to make the gray correlation analysis of S&T activities personnel, R&D personnel FTE, intramural expenditure for R&D and Patent Application Amount. Specific data are shown in **Table 1**.

According to the data calculation results of 1996-2014 in Beijing, it is shown that the correlation of S&T activities personnel, R&D personnel FTE, intramural expenditure for R&D with Patent Application Amount in the order: $r_1=0.747435; r_2=0.766385; r_3=0.572111$.The order of correlation degree is R&D personnel FTE, S&T

Table 1. Statistical data of innovation and development indicators in Beijing during 1996-2014.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Patent application	6595	6313	6321	7723	10,344	12,174	13,842	17,003	18,402	22,572
S&T activities personnel	265,552	273,161	237,127	229,584	261,113	240,609	257,326	270,921	301,202	383,153
Intramural expenditure for R&D	418,614	532,257	861,138	938,437	1,557,011	1,711,696	2,195,402	2,562,518	3,169,064	3,795,450
R&D personnel FTE	84,793	84,913	86,602	85,740	98,723	95,255	114,919	110,358	152,132	177,765
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Patent application	26,555	31,680	43,508	50,236	57,296	77,955	92,305	123,336	138,111	
S&T activities personnel	382,756	450,331	450,147	529,985	529,811	605,980	651,003	681,346	726,792	
Intramural expenditure for R&D	4,329,878	5,270,591	6,200,983	6,686,351	8,218,234	9,366,440	10,633,640	11,850,469	12,687,953	
R&D personnel FTE	168,875	204,668	200,080	191,779	193,718	217,255	235,493	242,175	245,384	

Intramural expenditure for R&D, Unit: million.

activities personnel and intramural expenditure for R&D.

According to the selection of affecting the main factor greater than 65% [7], then select R&D personnel FTE and S&T activities personnel which have close grey co-relationship with Patent Application Amount as indicators. First of all, time series method and GM(1,1) model are used to predict Patent Application Amount and R&D personnel FTE for years of 2015-2025. Followed by GM(1,N) model predicts the number of National S&T personnel in Beijing in 2015-2025.

3. GM(1,1) Model

GM(1,1) model, which is basing on the past and now known or uncertain information to establish one order grey model of a variable from the past extended to future. The GM(1,1) model is used to determine the trend of the development and changes in the future. Grey prediction does not pursue the effect of individual factors, which trying to find the inherent law of the influence of the random factors on the processing of the original data [8].

Specific algorithm is:

1) In this paper, the original data sequence is assumed to be $x^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right)$

The one-time accumulated generating sequence of $x^{(0)}$ is

$$x^{(1)} = AGOx^{(0)}, \tag{8}$$

where

$$x^{(1)}(k) = \sum_{m=1}^{k} x^{(0)}(m), k = 1, 2, \cdots, n. \tag{9}$$

2) The GM(1,1) parameters *a*, *b* of $x^{(0)}$, according to the following formula recognition

$$\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} = \left(B^{\mathrm{T}} B\right)^{-1} B^{\mathrm{T}} y_N \tag{10}$$

where

$$B = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -Z^{(1)}(n) & 1 \end{bmatrix}, y_N = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1). \tag{11}$$

3) GM(1,1) model:

The grey differential equation is:

$$x^{(0)}(k) + az^{(1)}(k) = b. \tag{12}$$

The whitening differential equation is:

$$\frac{\mathrm{d}x^{(1)}}{\mathrm{d}t} + ax^{(1)} = b. \tag{13}$$

Time response of the whitening equation is:

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)\mathrm{e}^{-ak} + \frac{b}{a} \tag{14}$$

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \quad . \tag{15}$$

4) GM(1,1) model accuracy (error) for the residual test.

Record $\hat{x}^{(0)}(k)$ as model value, $x^{(0)}(k)$ as actual value, $\varepsilon(k)$ as the relative residual values, then

$$\varepsilon(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \times 100\%, \ k = 2, 3, \cdots, n. \tag{16}$$

4. Beijing Patent Application Forecast

4.1. Time Series Analysis

According to historical data, time series forecasting method was used, the prediction model of Beijing patent application amount is obtained:

$$\begin{aligned} Y &= 4537.6e^{0.1867t} \\ R^2 &= 0.9942 \end{aligned} . \quad (17)$$

$t = 1$ for the year of 1997. The simulation value of patent application (**Table 2**) can be calculated through equation (17).

The average absolute relative error of model is 6.20%, which is less than 10.00%. Thus the model can be used. And the number of patent application for 2015-2025 in Beijing (**Table 3**) can be predicted by the model.

4.2. GM(1,1) Prediction Model

Matrix $\hat{a}$ can be obtained by calculating historical data of patent application in Beijing.

$$\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} -0.20352 \\ 6380.306 \end{bmatrix}. \quad (18)$$

Then the amount of patent application in Beijing Grey differential equation is:

$$x^{(0)}(k) - 0.20352 z^{(1)}(k) = 6380.306 . \quad (19)$$

Whitening equation is:

$$\frac{dx^{(1)}}{dt} - 0.20352 x^{(1)} = 6380.306 . \quad (20)$$

Thus model value of patent application for 2002-2008 in Beijing (**Table 4**) can be predicted.

The average absolute relative error of model is 7.18%, which is less than 10.00%. Thus the model can be used. And the number of patent application for 2015-2025 in Beijing (**Table 5**) can be predicted by the model.

4.3. The Average of the Two Prediction Results

The results of two groups are averaged. Thus the predict value of the patent application in Beijing in 2015-2025

Table 2. Comparison of the simulation value and the actual value of the patent application in Beijing (unit: piece).

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
Patent applications	6313	6321	7723	10,344	12174	13,842	17,003	18,402	22,572
Simulation value	5469.0	6591.6	7944.6	9575.4	11,540.9	13,909.9	16,765.1	20,206.4	24,354.1
Relative error	0.1337	−0.0428	−0.0287	0.0743	0.0520	−0.0049	0.0140	−0.0981	−0.0789
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Patent applications	26,555	31,680	43,508	50,236	57,296	77,955	92,305	123,336	138,111
Simulation value	29,353.1	35,378.3	42,640.2	51,392.8	61,942.0	74,656.5	89,981.0	108,451.0	130,712.2
Relative error	−0.1054	−0.1167	0.0199	−0.0230	−0.0811	0.0423	0.0252	0.1207	0.0536

Table 3. Prediction of patent application for 2015-2025 in Beijing (unit: piece).

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Predicted value	157,543	189,881	228,857	275,834	332,453	400,694	482,943	582,074	701,554	845,559	1,019,124

Table 4. Comparison of the simulation value and the actual value of the patent application in Beijing (unit: piece).

Year	2002	2003	2004	2005	2006	2007	2008
Actual value	13,842	17,003	18,402	22,572	26,555	31,680	43,508
Model value	11,534.8	14,138.2	17,329.4	21,240.8	26,035.0	31,911.3	39,114.0
Error value	0.1667	0.1685	0.0583	0.0590	0.0196	−0.0073	0.1010
Year	2009	2010	2011	2012	2013	2014	2010
Actual value	50,236	57,296	77,955	92,305	123,336	138,111	57,296
Model value	47,942.4	58,763.4	72,026.8	88,283.9	108,210.4	132,634.4	58,763.4
Error value	0.0457	−0.0256	0.0760	0.0436	0.1226	0.0397	−0.0256

Table 5. Prediction of patent application for 2015-2025 in Beijing (unit: piece).

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
predicted value	162,571	199,265	244,241	299,368	366,938	449,760	551,274	675,702	828,214	1,015,149	1,244,277

(**Table 6**) is obtained by taking average of the two prediction results.

5. Beijing R&D Personnel FTE Forecast

5.1. Time Series Analysis

According to historical data, time series forecasting method was used, the prediction model of Beijing R&D personnel FTE is obtained:

$$\begin{aligned} &Y = 71.451t^2 + 8845.8t + 59655 \\ &R^2 = 0.9452 \end{aligned} . \tag{21}$$

$t = 1$ for the year of 1996. The simulation value of Beijing R&D personnel FTE (**Table 7**) can be calculated through Equation (21).

The average absolute relative error of model is 8.23%, which is less than 10.00%. Thus the model can be used. And the number of R&D personnel FTE for 2015-2025 in Beijing (**Table 8**) can be predicted by the model.

5.2. GM(1,1) Prediction Model

Matrix $\hat{a}$ can be obtained by calculating historical data of R&D personnel FTE in Beijing.

$$\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} -0.06366 \\ 87514.36 \end{bmatrix}, \tag{22}$$

thus, grey differential equation is:

$$x^{(0)}(k) - 0.06366z^{(1)}(k) = 87514.36, \tag{23}$$

whitening equation is:

$$\frac{\mathrm{d}x^{(1)}}{\mathrm{d}t} - 0.06366x^{(1)} = 87514.36 . \tag{24}$$

Thus model value of R&D personnel FTE in Beijing for 1998-2014 in Beijing (**Table 9**) can be predicted.

The average absolute relative error of model is 9.68%, which is less than 10.00%. Thus the model can be used. And the number of R&D personnel FTE for 2015-2025 in Beijing (**Table 10**) can be predicted by the model.

5.3. The Average of Two Prediction Results

The results of two groups are averaged. Thus the forecast value of the R&D personnel FTE in Beijing in

Table 6. Prediction of patent application for 2015-2025 in Beijing.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Predicted value	160,057	194,573	236,549	287,601	349,695	425,226	517,108	628,888	764,884	930,354	1,131,700

Table 7. Comparison of the simulation value and the actual value of the R&D personnel FTE in Beijing (unit: one year).

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FTE	84,793	84,913	86,602	85,740	98,723	95,255	114,919	110,358	152,132	177,765
Simulation value	68,572	77,632	86,836	96,181	105,670	115,302	125,077	134,994	145,055	155,258
Relative error	0.1913	0.0857	−0.0027	−0.1218	−0.0704	−0.2105	−0.0884	−0.2232	0.0465	0.1266
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	
FTE	168,875	204,668	200,080	191,779	193,718	217,255	235,493	242,175	245,384	
Simulation value	165,604	176,094	186,726	197,501	208,419	219,479	230,683	242,030	253,519	
Relative error	0.0194	0.1396	0.0667	−0.0298	−0.0759	−0.0102	0.0204	0.0006	−0.0332	

FTE: full-time equivalent.

Table 8. Prediction of R&D personnel FTE for 2015-2025 in Beijing city (unit: one year).

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Predicted value	265,151	276,927	288,845	300,906	313,110	325,457	337,947	350,580	363,355	376,273	389,335

Table 9. Comparison of the simulation value and the actual value of the R&D personnel FTE in Beijing (unit: one year).

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006
Actual value	86,602	85,740	98,723	95,255	114,919	110,358	152,132	177,765	168,875
Model value	95,941	102,247	108,967	116,129	123,762	131,896	140,566	149,804	159,651
Error value	−0.1078	−0.1925	−0.1038	−0.2191	−0.0769	−0.1952	0.0760	0.1573	0.0546
Year	2007	2008	2009	2010	2011	2012	2013	2014	
Actual value	204,668	200,080	191,779	193,718	217,255	235,493	242,175	245,384	
Model value	170,144	181,327	193,245	205,946	219,482	233,908	249,282	265,667	
Error value	0.1687	0.0937	−0.0076	−0.0631	−0.0103	0.0067	−0.0293	−0.0827	

Table 10. Prediction of R&D personnel FTE for 2015-2025 in Beijing (unit: one year).

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Predicted value	283,128	301,737	321,569	342,705	365,230	389,235	414,818	442,083	471,140	502,106	535,108

2015-2025 (**Table 11**) is obtained by taking average of the two prediction results.

6. GM(1,N) Model

GM(1,N) model, which is based on past and present known or uncertain information to establish a one order N variables from the past to the future, to determine the development trend of the system in the future [9]. This model is based on the assumption that there is a causal relationship between the amount of patent application and the amount of scientific and technical personnel, R&D personnel FTE. According to the prediction results of the patent application and R&D personnel FTE, the number of scientific and technical personnel in the future can be predicted by **Table 12**.

1) GM(1,N) modeling, we first need to pre-test with a cover formula, which uses step ratio $\sigma(k)$ of modeling sequence and the size of subordinate interval to determine [10].

First, x_i is defined as Equation (25)

$$x_i^{(0)}(k) = x_i(k),\ i = 1,2,3;\ k = 1,2,\cdots,19, \tag{25}$$

the Covering formula is:

$$\sigma(k) = \frac{x_i^{(0)}(k-1)}{x_i^{(0)}(k)},\ \sigma(k) = \left(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}\right), \tag{26}$$

then, the selected sequence can be modeled.

2) For $x_i^{(0)}$ according to Equation (27) to generate $x_i^{(1)}$, that can be seen in **Table 13**.

$$x_i^{(1)} = \sum_{m=1}^{k} x_i^{(0)}(m) \tag{27}$$

$$x_i^{(1)} = AGOx_i^{(0)}. \tag{28}$$

a) For $x_i^{(1)}$,according to Equation (29) for the mean of processing as $z_1^{(1)}$.

$$z_1^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1) \tag{29}$$

$$z_1^{(1)} = \left(z_1^{(1)}(2), z_1^{(1)}(3), \cdots, z_1^{(1)}(19)\right). \tag{30}$$

b) Based on $x_i^{(1)}$ and $z_1^{(1)}$ has GM(1,N) data matrix B and data vector y_N,

Table 11. Prediction of R&D personnel FTE for 2015-2025 in Beijing.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
FTE	274,140	289,333	305,207	321,806	339,170	357,346	376,383	396,331	417,247	439,190	462,221

Table 12. Historical data of innovation evaluation in Beijing (Patent Application Amount, S&T activities personnel, R&D personnel FTE).

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Patent application (x1)	6595	6313	6321	7723	10,344	12,174	13,842	17,003	18,402	22,572
FTE (x2)	84,793	84,913	86,602	85,740	98,723	95,255	114,919	110,358	152,132	177,765
S&T personnel (x3)	265,552	273,161	237,127	229,584	261,113	240,609	257,326	270,921	301,202	383,153
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Patent application (x1)	26,555	31,680	43,508	50,236	57,296	77,955	92,305	123,336	138,111	
FTE (x2)	168,875	204,668	200,080	191,779	193,718	217,255	235,493	242,175	245,384	
S&T personnel (x3)	382,756	450,331	450,147	529,985	529,811	605,980	651,003	681,346	726,792	

$$B=\begin{bmatrix}-z_1^{(1)}(2) & x_2^{(1)}(2) & x_3^{(1)}(2)\\ -z_1^{(1)}(3) & x_2^{(1)}(3) & x_3^{(1)}(3)\\ \vdots & \vdots & \vdots\\ -z_1^{(1)}(19) & x_2^{(1)}(19) & x_3^{(1)}(19)\end{bmatrix} \tag{31}$$

$$y_N=\left[x_1^{(0)}(2)\quad x_1^{(0)}(3)\quad \cdots \quad x_1^{(0)}(19)\right]^{\mathrm{T}}. \tag{32}$$

c) According to the method of least squares identification algorithm

$$\hat{a}=\left(B^{\mathrm{T}}B\right)^{-1}B^{\mathrm{T}}y_N. \tag{33}$$

Thus,

$$\hat{a}=\left[a\quad b_2\quad b_3\right]^{\mathrm{T}}=\left[-0.1906\quad -0.0346\quad 0.0148\right]^{\mathrm{T}} \tag{34}$$

Then the model is:

$$\hat{x}_1^{(0)}(k)=\sum_{i=2}^{3}b_i x_i^{(1)}(k)-az_i^{(1)}=-0.0346x_2^{(1)}(k)+0.0148x_3^{(1)}(k)+0.1906z_1^{(1)}(k). \tag{35}$$

Comparing the actual value with the model value, fitted values and errors of the GM(1,n) prediction model (**Table 14**) can be obtained.

The average absolute relative error of model is 2.03%, which is less than 10.00%. Based on the forecast value of the amount of patent application and R&D personnel full time equivalent, the model is used to predict the number of scientific and technological personnel in Beijing (**Table 15**).

Table 13. The results of AGO for $x_i^{(0)}$.

k	1	2	3	4	5	6	7	8	9	10
$x_1^{(1)}$	6595	12,908	19,229	26,952	37,296	49,470	63,312	80,315	98,717	121,289
$x_2^{(1)}$	84,793	169,706	256,308	342,048	440,771	536,026	650,945	761,303	913,435	1,091,200
$x_3^{(1)}$	265,552	538,713	775,840	1,005,424	1,266,537	1,507,146	1,764,472	2,035,393	2,336,595	2,719,748
k	11	12	13	14	15	16	17	18	19	
$x_1^{(1)}$	147,844	179,524	223,032	273,268	330,564	408,519	500,824	624,160	762,271	
$x_2^{(1)}$	1,260,075	1,464,743	1,664,823	1,856,602	2,050,320	2,267,575	2,503,068	2,745,243	2,990,627	
$x_3^{(1)}$	3102,504	3,552,835	4,002,982	4,532,967	5,062,778	5,668,758	6,319,761	7,001,107	7,727,899	

Table 14. Fitted values and errors of the GM(1,n) prediction model.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
Actual value	6313	6321	7723	10,344	12,174	13,842	17,003	18,402	22,572
Fitted values	3957	5673	7440	9609	120,185	14,326	17,454	20,017	23,437
Residual error	0.3731	0.1026	0.0366	0.0711	0.0129	−0.0350	−0.0265	−0.0878	−0.0383
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Actual value	26,555	31,680	43,508	50,236	57,296	77,955	92,305	123,336	138,111
Fitted values	27,935	33,062	39,961	50,098	61,478	75,812	93,517	115,763	142,936
Residual error	−0.0520	−0.0436	0.0815	0.0028	−0.0730	0.0275	−0.0131	0.0614	−0.0349

According to the time sequence and GM(1,1) prediction model, taking average value of each results of patent applications and R&D personnel FTE are took into GM(1,n) model to predict Beijing 2015-2025 S&T activities personnel (**Table 15**). The prediction results were analyzed, the number of Beijing Science and technology activities is exponential growth trends such as **Figure 1**. The results of a number of scientific and technological activities for the next ten years of Beijing prediction has certain reference value, also for the national science and technology talent investment policies provide certain basis.

7. Conclusions

The prediction of the S&T activities personnel is an important issue for controlling and monitoring education reforming. The training of scientific and technical personnel is a basic project of "the strategy of developing the country through science and education", "the strategy of talent powerful nation" and "national innovation system construction". The study on this issue is meaningful and valuable for controlling, monitoring and improving National Science and technology innovation ability. This paper aims to use prey theory to predict the condition of S&T activities personnel, R&D personnel FTE, intramural expenditure for R&D and Patent Application Amount in recently for the last ten years.

- GM(1,1) and GM(1,N) are introduced in this paper. In comparison, the GM(1,N) model has better predictability under the condition of scanty data than GM(1,1) [11]. We need to collect relevant data of variables that involved, then according to the GM(1,N) model to predict the target variables [12].
- Data analysis showed that the number of science and technology activities in Beijing showed an exponential growth trend. According to the characteristics of the index function, the total number of people engaged in

Table 15. Prediction of S&T activities personnel for 2015-2025 in Beijing.

Year	2015	2016	2017	2018	2019	2020
Predicted value	680,208	725,040	773,663	826,683	884,834	949,005
Year	2021	2022	2023	2024	2025	
Predicted value	1,020,271	1,099,941	1,189,606	1,291,208	1,407,114	

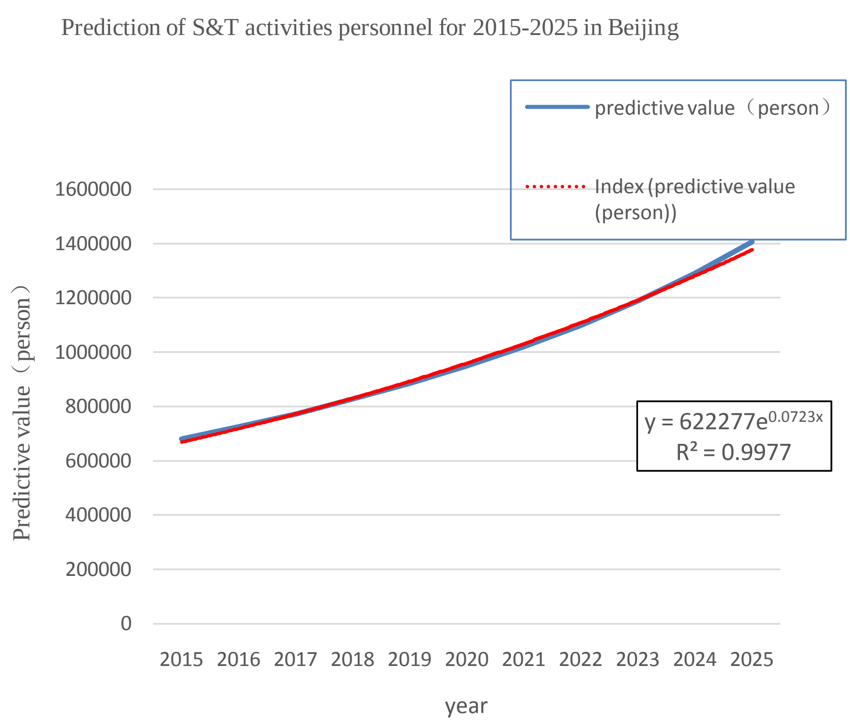

Figure 1. Prediction of S&T activities personnel for 2015-2025 in Beijing.

scientific research in China is growing at a faster pace. The number of scientific and technical personnel directly represents the status of scientific research in a country. Higher education is the main bearer of innovation oriented national talent cultivation and scientific research. The number and quality of scientific and technical personnel as the main body of scientific and technological innovation are the focus of all the countries in the world. Therefore, the national policy should ensure that the number of scientific and technical personnel. At the same time, China should strengthen the evaluation of the quality of scientific and technical personnel, improve the scientific and technological personnel of scientific research products, and thus enhance the country's ability to innovate.

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