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Grey Correlation Analysis on the Total Amount of Power Consumption and That of Different Industries in China

Jie Yao and Wei Zhu
Department of Economy and Management, Northeast Dianli University, Jilin 132012, China

Abstract: This study has made deep research on the relationship between the total amount of power consumption and that of different industries in China from 2000 to 2009. On this basis, the grey correlation degrees between the total amount of power consumption and that of different industries have been calculated by applying grey correlation method, so that we can know the different effects that each industry has had on the total power consumption. Finally, this study set up a grey correlation model GM (1, n) to forecast China's total amount of power consumption.

Keywords: Grey correlation analysis, grey modeling, power consumption

INTRODUCTION

In recent years, with the rapid economic development of China, people's living standards have been improved significantly; the power consumption of the whole society has been showing a steady speed up trend. Forecasting the amount of power consumption well can make the development of the power industry adapt to the demand of national economic and social development better and can also promote the development of the power industry itself. In this study, the grey relation theory are applied to make the quantitative analysis on the effect that different industries have on the total power consumption and calculate the correlation degree between the power consumption of different industries and the total amount. According to the result, it finds out the important correlated variables that can be used in the grey relational model and then sets up the grey GM (1, n) model, which is the basis for forecasting the total amount of power consumption. Sun (2010) have a research of the grey relational analysis method and its application. Liu and Xie (2010) study the grey system theory and its applications (4th edition). Wang (2009) study the gray system assembly.

This study has made deep research on the relationship between the total amount of power consumption and that of different industries in China from 2000 to 2009. On this basis, the grey correlation degrees between the total amount of power consumption and that of different industries have been calculated by applying grey correlation method, so that we can know the different effects that each industry has had on the total power consumption. Finally, this study set up a grey correlation model GM (1, n) to forecast China's total amount of power consumption.

GREY CORRELATION ANALYSIS ON THE POWER CONSUMPTION OF DIFFERENT INDUSTRIES IN CHINA

By analyzing the data in China's statistical yearbook, we can find that the main industries that have effect on the total amount of China's power consumption are agriculture, forestry, animal husbandry, fishery, subordinated, industry, construction, transportation, storage and the postal service, wholesale, retail and accommodation, catering, other industries, life consumption etc. We will calculate the correlation degree between the power consumption of different industries and the total amount in order to find out which industries have great effect on the total amount of power consumption.

Grey correlation analysis theory: Suppose we have l, sub-factors (x_1, x_2, ..., x_l) that are related with the main factor (x_0). All these sub-factors have n series of original data and the series of data composite the following sequence.

- Main factors: x_0 (i) (i =1, 2, ..., n)
- Sub-factors: x_k (i) (k = 1, 2, ..., l i = 1,2,...,n)

For comparison, the data is standardized. Let:

$$\overline{x_0}(i)=\frac{1}{n}\sum_{i=1}^{n}x_o(i)\quad \overline{x_k}(i)=\frac{1}{n}\sum_{i=1}^{n}x_k(i)$$

After being standardized, we can have:

$$x_0(i)=\frac{x_0(i)}{\overline{x_0}}\quad x_k(i)=\frac{x_k(i)}{\overline{x_0}}$$

Corresponding Author: Jie Yao, Department of Economy and Management, Northeast Dianli University, Jilin 132012, China

Table 1: Correlation coefficients between china's total amount of power consumption and that of different industries from 2000 to 2009

Factors	x1	x2	x3	x4	x5	x6	x7
2000	0.2855	0.8525	0.4984	0.5189	0.8141	0.6924	0.7417
2001	0.2412	0.8223	0.9529	0.4736	0.9738	0.6308	0.6779
2002	0.2861	0.8696	0.9452	0.4887	0.9197	0.5733	0.7598
2003	0.4716	0.9345	1.000	0.4344	0.5684	0.6227	0.9804
2004	0.8659	0.9508	0.8739	0.4402	0.4672	0.5416	0.6566
2005	0.7214	0.926	0.5773	0.5852	0.959	0.6184	0.6757
2006	0.4492	0.8815	0.5897	0.3982	0.7719	0.529	0.6696
2007	0.2612	0.7312	0.5395	0.3562	0.5038	0.7537	0.5063
2008	0.1672	0.979	0.4706	0.3796	0.6852	0.4176	0.4246
2009	0.154	0.7886	0.2781	0.3779	0.7993	0.2607	0.3206
Correlation degree	0.3903	0.8736	0.6726	0.4453	0.7462	0.564	0.6413

Then define:

$$\xi(k)=\frac{\min_i\min_k\left|x_o(k)-x_i(k)\right|+\rho\max_i\max_k\left|x_o(k)-x_i(k)\right|}{\left|x_o(k)-x_i(k)\right|+\rho\max_i\max_k\left|x_o(k)-x_i(k)\right|} \quad (1)$$

To be the correlation coefficient between x_0 and x_i at k point.
In formula 1, we let ρ equal to 0.2.

By integrating the correlation coefficients of each point, we can get the correlation degree of entire x_i curve and reference curve x_0:

$$r_i=\frac{1}{n}\sum_{i=1}^{n}\xi_i(k) \quad (2)$$

r_i is a very important figure to measure the correlation degree of different factors. Obviously, for the factor itself, the correlation degree equal to 1 and the correlation degree will be bigger than 0.5 if the main factor has some correlation with the sub-factors. If r_i is bigger than r_j, the correlation degree of x_i to x_0 is greater than that of x_j to x_0.

Application of gray relation theory in the correlation analysis of power consumption: In the grey correlation analysis of domestic power consumption, we select the total amount of power consumption as the main factor x_0 and take the power consumption of agriculture, forestry, animal husbandry, fishery, water conservancy, industrial, construction, transportation, storage and postal industry, wholesale, retail and residential food and beverage industry, other industries, as the sub-factors x_i.

We have applied the gray theory to calculate the correlation degree between the total amount of power consumption and that of different industries. The results have been shown in Table 1. In Table 1, x_1 represents Agriculture, forestry, animal husbandry, fishery, water conservancy, x_2 represents industrial, x_3 represents the construction industry, x_4 represents transportation, storage and postal industry, x_5 represents wholesale, retail trade and accommodation, catering, x_6 represents other industries, x_7 represents consumption.

It can be seen from Table 1 that the correlation degree of the following industries, such as industry (0.8736), construction (0.6726), wholesale and retail trade and accommodation, food and beverage industry (0.7462), other industry (0.5640), consumption (0.6413) are greater than 0.5, which show that the impact of these industries on China's total power consumption cannot be ignored. Since the correlation degree of the following industries, such as storage and postal industry (0.4453), agriculture, forestry, animal husbandry, fishery, water conservancy industry (0.3903) is less than 0.5, therefore they will not be used for further analysis.

Setting up the gray correlation model for forecasting the total power consumption: According to the correlated factors of power consumption identified above, we can easily select the following 4 industries to make further analysis. They are industry, construction and wholesale, retail and hotel industry and consumption. By analyzing the data of these four industries, we set up the grey correlation model GM (1, n) for forecasting the total amount of China's power consumption.

Gray model GM (1, n): The series, such as x_1, x_2,... x_l all have n corresponding raw data, namely,

$x_i^{(0)}$ = [$x_i^{(0)}(1)$,$x_i^{(0)}(2)$, ……, $x_i^{(0)}(n)$] (i=1,2,.....,□n□)

$x_i^{(0)}$ is accumulated and then we could generate the following series:

xi (1) = [xi (1)(1),xi (1)(2),...,xi (1)(n)]

$$x^{(1)}{}_i(k)=\sum_{m=1}^{k}x^{(0)}{}_i(m) \qquad (i=1,2,......,\ell) \quad (3)$$

After that we can set up the differential equation:

$$\frac{dx_1^{(1)}}{dt}+ax_1^{(1)}=\sum_{i=2}^{l}b_iX_i^{(1)} \quad (4)$$

We can get the estimate of a, b, b_3, ..., b_l □by using the least square method. Let:

$\hat{a}$ = (a , b_1, b_2, … ,bl)^T

$$B=\begin{bmatrix} -\frac{1}{2}[x_1^{(1)}(1)+x_1^{(1)}(2)] & x_2^{(1)}(2) & \ldots\ldots & x_l^{(1)}(2) \\ -\frac{1}{2}[x_1^{(1)}(2)+x_1^{(1)}(3)] & x_2^{(1)}(3) & \ldots\ldots & x_l^{(1)}(3) \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ -\frac{1}{2}[x_1^{(1)}(n-1)+x_1^{(1)}(n)] & x_2^{(1)}(n) & \ldots\ldots & x_l^{(1)}(n) \end{bmatrix}$$

Y = [x1(0) (2), x1(0) (3),..., x1(0) (n)]T

By using the least square method:

$$\hat{\alpha} = (BB^T)^{-1} B^T Y \tag{5}$$

We can obtain the estimate of a, b, b_3,...,b_l□. Solve the differential equations and obtain the gray model GM (1, n):

$$\hat{x}_1^{(1)}(k+1)=[x_1^{(0)}(1)-\frac{1}{a}\sum_{i=2}^{l}b_i x_i^{(1)}(k+1)]e^{-ak}+\frac{1}{a}\sum_{i=2}^{l}b_i x_i^{(1)}(k+1) \tag{6}$$

The analogy value of $x_1^{(0)}(k)$ is:

$$\hat{x}_1^{(0)}(k+1) = \hat{x}_1^{(1)}(k+1) - \hat{x}_1^{(1)}(k)$$

The application of gray model GM (1, n) in power consumption analysis: According to the calculation method of model GM (1, n), in order to undermine the fluctuation of the data, reduce the randomness, adjust the change trend of the data, make it meet or close to the needs of the decision, we have made smooth treatment to the following series of data in advance. They are the total power consumption of China $x_1^{(0)}$, the power consumption of industry $x_2^{(0)}$, that of construction $x_3^{(0)}$, that of wholesale,retail and accommodation, catering $x_4^{(0)}$, that of consumption $x_5^{(0)}$. Namely:

$$x^{(0)}(k) = [x(k-1)+2x(k)+x(k+1)]/4 \tag{8}$$

In the formula above, x (k-1), x (k), x (k+1) represent the (k-1) th, kth, (k+1) th original data respectively, $x^{(0)}(k)$ means the kth data after processing.

Then we can get the forecasting model GM (1, 5) of this problem:

$$\begin{aligned}\hat{x}_1^{(1)}(k+1) &= [(x_1^{(0)}-\frac{b_1}{a}x_2^{(1)}(k+1)-\frac{b_2}{a}x_3^{(1)}(k+1)-\frac{b_3}{a}x_4^{(1)}(k+1)-\frac{b_4}{a}x_5^{(1)}(k+1)]e^{-ak} \\ &\quad +\frac{b_1}{a}x_2^{(1)}(k+1)+\frac{b_2}{a}x_3^{(1)}(k+1)+\frac{b_3}{a}x_4^{(1)}(k+1)+\frac{b_4}{a}x_5^{(1)}(k+1) \\ &= [13471.38-0.9715x_2^{(1)}(k+1)+17.8626x_3^{(1)}(k+1)-4.2922x_4^{(1)}(k+1) \\ &\quad -2.7585x_5^{(1)}(k+1)]e^{2.2357k}+0.9715x_2^{(1)}(k+1)-17.8626x_3^{(1)}(k+1) \\ &\quad +4.2922x_4^{(1)}(k+1)+2.7585x_5^{(1)}(k+1)\end{aligned} \tag{9}$$

Substituting the generated value into the formula above, we can get the analog value $\hat{x}_1^{(1)}$ of $x_1^{(1)}$, as shown in Table 2.

Table 2: Analog value of generated series x1(1)

K	1	2	3	4	5
$\hat{x}_1^{(1)}(k)$	13471.38	25967.79	43588.07	62841.61	84727.52
K	6	7	8	9	10
$\hat{x}_1^{(1)}(k)$	109680.43	138182.62	170130.41	204745.36	241617.61

Table 3: Analog value and residuals of x1(0)

K	$x_1^{(0)}$	$\hat{x}_1^{(0)}$	$\xi_1^{(0)} = x_1(0) - \hat{x}_1^{(0)}$	Relative error %
1	13471.38	13471.38	0	0
2	14767.44	12496.41	2271.03	15.38
3	16581.99	17620.28	-1038.29	-6.26
4	19091.51	19253.53	-162.02	-0.85
5	21978.68	21885.91	92.77	0.42
6	25110.03	24952.91	157.12	0.63
7	28707.03	28502.20	204.83	0.71
8	32138.23	31947.79	190.44	0.59
9	34706.68	34614.95	91.73	0.26
10	37032.20	36872.26	159.94	0.43

Do cumulative reduction of $\hat{x}_1^{(1)}$ to get the analog value $\hat{x}_1^{(0)}$ of $x_1^{(0)}$, namely:

$$\hat{x}_1^{(0)}(k) = \hat{x}_1^{(1)}(k) - \hat{x}_1^{(1)}(k-1) \tag{10}$$

The calculation results and the residuals calculated are shown in Table 3. From the table, we can notice that the relative error is less than 1%. And according to the model reference table of accuracy class, it belongs to the first level accuracy.

Prediction of China's total power consumption using gray model GM (1, n): According to the average growth rate of the following four industries in recent years, such as 12.1% of industry, 11.92% of construction, 12.56% of wholesale, retail and accommodation, catering, 12.68% of life consumption, the power consumption of these four industries in 2010 is estimated to be 30103.89, 472.19, 1279.58, 5489.81 one hundred million kw/h, respectively:

$x_2^{(0)}(11) = 30103.89$ $x_2^{(1)}(11) = x_2^{(1)}(10) + x_2^{(0)}(11) = 178817.48 + 30103.89 = 208921.37$
$x_3^{(0)}(11) = 472.19$ $x_3^{(1)}(11) = x_3^{(1)}(10) + x_3^{(0)}(11) = 472.19 + 2495.07 = 2967.26$
$x_4^{(0)}(11) = 1279.58$ $x_4^{(1)}(11) = x_4^{(1)}(10) + x_4^{(0)}(11) = 1279.58 + 7379.55 = 8677.13$
$x_5^{(0)}(11) = 5489.81$ $x_5^{(1)}(11) = x_5^{(1)}(10) + x_5^{(0)}(11) = 29259.75 = 5489.81 = 34749.56$

Substituting the data calculated above into model GM (1, 5), we can get:

$\hat{x}_1^{(1)}$ (11) = [13471.38−0.9715 × $x^{(1)}_2$ (11) + 17.8626×$^{(1)}{}_3$ (11)−4.2922×$^{(1)}{}_4$(11)−2.7585×$^{(1)}{}_5$ (11)]e$^{-22357\times10}$ +0.9715 ×$^{(1)}{}_2$ (11)−17.8626 ×$^{(1)}{}_3$ (11)+4.2922×$^{(1)}{}_4$ (11)+ 2.7585×$^{(1)}{}_5$ (11) = [13471.38 −0.9715 ×208921.37 +17.8626×2967.26−4.2922×8677.13−2.7585× 4749.56] e−$^{22357\times10}$0.9715×208921.37−17.8626×2967.26+4.2922 ×8677.13+2.7585× 34749.56 = 283064.84

Thus, we have:

$$\hat{x}_1^{(0)} = \hat{x}_1^{(1)}(11) - \hat{x}_1^{(1)}(10) = 283064.84 - 241617.61 = 41447.23$$

From the decade forecast value above, we can find that the error percent between the gray forecast value and the actual one is 1.13%, so we can draw:

$$\hat{x}_1^{(0)}(11) = \hat{x}_1^{(0)}(11)\times(1+1.13\%) = 41915.58$$

That is, China's power consumption in 2010 is 4.191558 trillion kw/h.

CONCLUSION

By applying the gray system theory and gray model GM (1, n) into the analysis of China's power consumption, we can draw the following conclusion.

Firstly, through the grey correlation analysis between the total amount of power consumption and that of different industries, we can find that the following industries have great impact on China's power consumption. They are industry, construction, transportation, storage and the postal service, wholesale, retail and accommodation, catering, other industries and life consumption. We should pay more attention to these industries when carrying out energy conservation and emissions reduction work of the industry.

Secondly, during the process of setting up the model GM (1, n), we have been using the data of those industries that have high correlation degree in the grey correlation analysis. By processing the data more smoothly, we can make the accuracy of the model much higher so that it can be used for forecasting the annual total amount of power consumption in the future.

The gray model can not only be used for forecasting next year's total power consumption, but also providing some guidance for the electric power department to plan for next years' work better. But we also know that the relationship between different influence factors is very complex, how to make it clear and improve the forecast precision of the model will be the main content for us to continue to study in the future.

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