

Forecast The Insurance Policy Under Extreme Weather Using the Gray Forecasting Model

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Abstract. Extreme-weather events have posed a great threat to the profitability of insurers and affordability of property owners. To mitigate the uncertain risk introduced by hurricanes, droughts, and plenty of other extreme weather, an insurance company decision making model is built. In the first stage, a combined model of CRITIC weight method and the Analytic Hierarchy Process (AHP simplified version) is used to calculate the weight of the specific indicators that impact the levels of underwriting risk. In the second stage, based on the indicators with the most weight calculated above, a gray forecasting model for Insurance Company is established to predict the underwriting risk in countries with adverse weather condition. It can be shown in the prediction results that all stage ratios of the translation transformed sequence are within the interval (0.834, 1.199). Therefore, the insurance companies should insure in areas where extreme weather events increase, which benefits their profits.

Keywords: CRITIC, AHP, Forecasting Model.

1. Introduction

Extreme weather events are a crisis for property owners and insurance companies. [1,2] In recent years, the global cost of more than 1,000 extreme weather events has exceeded \$1 trillion [3]. After that, the related losses due to extreme weather, such as floods and hurricanes, are likely to increase further. In 2022, the insurance industry faced a 115% increase in natural disaster claims over the 30-year average. As a result, insurance costs are rising rapidly, and insurers are changing how and where they write policies [4]. Insurance is becoming more expensive and harder to find, and the insurance industry is facing a crisis in insurer profitability and affordability. Besides, there has been few related research in previous study, most of the articles about the insurance policy under the extreme are focus on the present conditions about the relationship between the insurance policy and the weather[5,6]. There is a little forecasting about the changes of the insurance policy on the extreme weather and there is few research that take the insurance company as the main body of research and pay attention to the interests of the insurance company's underwriting, so it is extremely essential to predict the risk of extreme weather in different regions. Traditional prediction methods are based on linear regression, such as time series method, analysis method and pattern recognition method have defects of respectively. Therefore, the results based on gray forecasting will be important to the assessment of future underwriting risks.

2. The basic fundamental of model

2.1. The structure of AHP-CRITIC

Insurance companies are still ultimately motivated by profit. A risk assessment model is built to answer the question of whether insurance companies should insure in areas with frequent extreme weather events. The insurance company's choice of whether to undertake insurance in areas with frequent extreme weather is still based on the profit earned by the insurance company. The cost factors that affect the Profit of Insurance Company (PIC) are mainly divided into the following three categories: Personal Damage Compensation (PDC), Facility Damage Loss (FDL) and Land Insurance

Loss (LIL). These three parts are collectively referred to Insured amount. Taking the Resident Insured Amount (RIA) as the Revenue of Insurance Company (RIC) of the insurance company. However, at present, there is no unified refined measurement and detailed indicators, and the specific indicator selections are various.

The analytical hierarchy process (AHP) is a assessment method which has demonstrated suitability and accuracy when employed to evaluate and analyze risks of the extreme weather globally [7].

$$\omega_i' = \sqrt[n]{a_{i1}a_{i2} \cdots a_{in}} \quad (1)$$

The AHP method provides a systematic framework for assigning weights and evaluating the impact of each parameter involved in the overall risk assessment, even when data is limited. This ensures that the assessment is both comprehensive and nuanced, considering the diverse aspects that contribute to extreme weather frequency.

The CRITIC method is considered as a better way to get the weight than the entropy and standard deviation methods. Similar to most objective weighting methods, CRITIC uses the proportion of information entropy to represent the weight [8].

$$C_j = S_j \times R_j, W_j = \frac{C_j}{\sum_{j=1}^p C_j} \quad (2)$$

2.2. The Weight Composition of AHP-CRITIC

The essence of insurance companies is to make profit, as a consequence, a time forecast model is established to calculate the profit of writing insurance in some high-risk areas, which is revenue minus cost, and the formula is written as profit = revenue-cost. The income is the insurance amount, and the cost is divided into two parts. The first part is the frequency of extreme weather, and the occurrence frequency can be listed. The second part is the impact of extreme weather damage factors, the more disasters occur, the more insurance is paid out.

To assess the proportion of factors that influence the number of disasters, we looked for the average annual temperature, carbon dioxide emissions, methane emissions, total population, and number of disasters (destructive power).

Mean Annual Temperature (MAT): Mean annual temperature is the arithmetic mean of the daily mean temperature for each day of the year. In fact, the mean annual temperature is usually calculated by adding up the average temperature of the months of the year and dividing by 12.

Carbon Dioxide Emissions (CDE): Carbon dioxide emissions are the average green-house gas emissions generated in the production, transportation, use and recycling of the product. Carbon dioxide emissions can be calculated using the formula $E = P \times C$, where E represents carbon dioxide emissions, P represents energy consumption, and C represents carbon content per unit of energy.

Methane Emissions (ME): Methane emissions may contribute to global warming, increased precipitation, increased heavy rain events, increased cloud cover, reduced low temperature events.

Gross Population (GP): Gross population is also known as the total population. It refers to the sum total of all living individuals within a certain time point and a certain geographical range. As long as there is an independent life activity, it is included in gross population.

Therefore, we use the CRITIC weight method for objective analysis, and then use the Analytic Hierarchy Process (AHP simplified version) for subjective analysis, and finally analyze the best index. Through the weight structure, the weight that combines subjectivity and objectivity is established to help analyze whether an insurance company should write insurance in an area with frequent extreme weather events.

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analyze whether an insurance company should write insurance in an area with frequent extreme weather events.[9]

The AHP maybe biased due to psychological factors of the decision maker, while objective weighting methods such as CRITIC do not take into account the uniqueness of the problem. The decision model can be obtained by optimizing $\min \|\sum_{k=1}^L a_k w_k^T - w_i^T\|_2, i=1,2$ to minimize the divergence of w and w_k .

From the differential properties of the matrix [10], the optimal first order derivative of the decision model satisfies the condition:

$$\begin{bmatrix} W_1 & W_1^T W_1 & W_2^T \\ W_2 & W_1^T W_2 & W_2^T \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} W_1 & W_1^T \\ W_2 & W_2^T \end{bmatrix} \quad (3)$$

Also normalized to α_k and the weight matrix can be derived:

$$a_i^* = \frac{|a_i|}{\sum_{k=1}^L |a_k|}, \omega^* = \sum_{k=1}^L a_k^* \omega_k^T \quad (4)$$

And the final integrated weights W^* is:

$$WG = (0.186, 0.0322, 0.211, 0.281) T \quad (5)$$

2.3. The basic fundamental of gray forecasting model

According to the theory of gray system, although the physical appearance is complicated, it always has the overall function, so it must contain some internal law. The key is how to choose the right way to dig and use it. Gray system seeks its change rule through the arrangement of original data, which is a way to explore the realistic state of data, namely the production of gray sequence. All gray sequences can weaken their randomness and show their regularity through some generation. GM (1, 1) is a first-order differential equation model commonly used in gray models. In this paper, we use the enhanced GM (1, 1) model with other influencing factors to forecast the annual extreme weather insurance profits of American insurance companies. A gray forecast model is built as follow:

Define $X(0)$ as the original data series of the annual extreme weather insurance profits of American insurance companies from 2011 to 2020:

$$X(0) = \{X(0), X(0), X(0) \dots X(0)\} \quad (6)$$

And then we get the whitened equation:

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = b \quad (7)$$

where, $X^{(1)}$ is the cumulative generating operation sequence of $X^{(0)}$.

Then we use the least square method (OLS) to obtain parameters a and b as:

$$\hat{a} = (BTB)^{-1}BTY \quad (8)$$

Were

$$B = \begin{bmatrix} -z_2^{(1)} & 1 \\ -z_3^{(1)} & 1 \\ \dots & \dots \\ -z_n^{(1)} & 1 \end{bmatrix} Y = \begin{bmatrix} X_2^{(0)} \\ X_3^{(0)} \\ \dots \\ X_n^{(0)} \end{bmatrix} \quad (9)$$

$$Z_k^{(1)} = 0.5(X_k^{(1)} + X_{k-1}^{(1)}) \quad (10)$$

The respective time response sequence of the model is:

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

$$k=1,2,3,\dots,n-1 \quad (11)$$

We can get to $\hat{x}_{k+1}^{(1)}$, and then we can subtract to get to $\hat{x}^0$.

$$\hat{x}_k^0 = \{ \hat{x}_k^1 - \hat{x}_{k-1}^1 \} \quad (12)$$

To test the model, we define the gray forecasting sequence as:

$$\hat{X}^{(0)} = \{ \hat{X}_1^{(0)}, \hat{X}_2^{(0)}, \hat{X}_3^{(0)} \dots \hat{X}_n^{(0)} \} \quad (13)$$

Residuals can be obtained:

$$e_k = x_k^0 - \hat{x}_k^0, k=1,2,\dots,n \quad (14)$$

Calculate the variance S_1 of the original sequence x^0 and the variance S_2 of the residual e :

$$S_1 = \frac{1}{n} \sum_{k=1}^n (x_k^0 - \bar{x})^2, S_2 = \frac{1}{n} \sum_{k=1}^n (e_k^0 - \bar{e})^2 \quad (15)$$

Finally, the test error ratio of S_1 and S_2 is calculated:

$$C = \frac{S_2}{S_1} \quad (16)$$

3. Analysis of experimental results

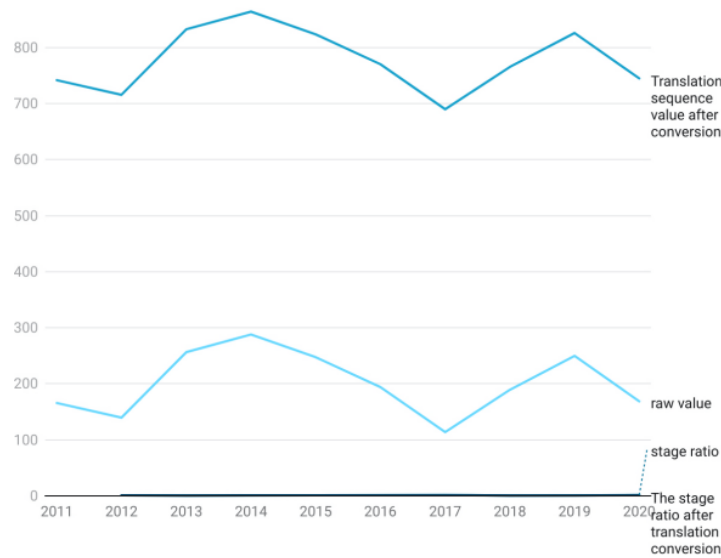


Figure.1. Test result chart of level ratio



Figure.2. Model fitting result

As shown in figure.1. and figure.2., a general idea of whether insurance companies should cover areas where extreme weather is increasing can be got [11]. To help insurers make decisions, using the gray forecasting model to predict whether insurers should cover areas where extreme weather events are on the rise. As can be seen from the results that all stage ratios of the translation transformed sequence are within the interval (0.834, 1.199), indicating that the translation transformed sequence is suitable for constructing the gray forecasting model in Table.1.

Table.1. Model prediction result

Prediction order	Predicted value
1	186.154
2	182.401
3	178.666
4	174.949
5	171.250
6	167.570

The above table shows the prediction result table of the gray forecasting model. Combining the results from the previous models, it can be seen that insurance companies should insure in areas where extreme weather events increase, which benefits their profits.

4. Conclusion

From the above, insurance companies should choose to cover more frequently in countries where extreme weather occurs, so that they can choose to take risks before periods of extreme weather.[12] And from the result, it can be concluded that insurance companies should cover in places where extreme weather is likely to increase in the future, so it is feasible for insurance companies to cover in areas where extreme weather events will increase.

According to the theory of gray system, although the physical appearance is complicated, it always has the overall function, so it must contain several internal **laws**.[13] The key is how to choose the right way to dig and use it. Gray system seeks its change rule through the arrangement of original

data, which is a way to explore the realistic state of data, namely the production of gray sequence. All gray sequences can weaken their randomness and show their regularity through a set of generation. The experimental results show that the gray forecasting model has good predictability and robustness, and has a certain practical application value.

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