Evaluation Of Property Insurance Risk Caused by Disasters Based on Analytic Hierarchy Process and Entropy Weight Method

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Abstract. In recent years, the frequent occurrence of natural disasters and extreme weather events has become a crisis for insurance companies, as the choice of underwriting policies can greatly impact their interests. In order to comprehensively assess the risks underwritten in a specific region, this paper establishes a model for evaluating the insurance risks of natural disaster property. Firstly, it analyzes the premium amount based on the relationship between demand and price. Then, by employing multiple indicators, it evaluates the severity of disasters in a region using Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM). Furthermore, it utilizes the Grey Prediction Theory to forecast the frequency of disasters and assess the compensation in that region. Finally, the underwriting risks are analyzed by combining premiums and compensation. Japan and Chile are taken as examples in this study, both exhibiting high underwritten risks, with Chile surpassing Japan. Because Japan has more Emergency Relief Funds, a higher level of disaster prevention education and a significantly larger population than Chile, resulting in smaller losses from disasters and higher insurance payouts.

Keywords: Property Insurance, AHP, EWM, Grey Forecast.

1. Introduction

With the changing of the global climate, the impact of extreme-weather events is increasing, leading to escalating losses caused by various disasters. This has posed a serious crisis for both property owners and insurance companies. Due to the complexity of global weather patterns, insurance companies are unable to effectively manage the risks, which caused a widening insurance protection gap all over the world. Thus, it is an urgent need to establish a model that can help insurance companies to predict the risks of natural disasters and reduce the insurance protection gap. Grey system theory is employed to predict the occurrence of disasters [1]. Liu Jiankang and his colleagues analyzed data from Hunan province, China for the years 2010 to 2020, including disaster-related deaths, economic losses, total population, and GDP, conducting a study on the acceptable level of natural disaster risk [2]. Zou Lihua utilized the Monte Carlo method for disaster-induced aggregate loss simulation, integrating it with BDT interest rate term structure for the pricing analysis of catastrophe bonds [3]. This paper first evaluates insurance premiums, then selects relevant indicators and uses the Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM) [4] to obtain the weights of each indicator. Based on these indicators, the disaster losses of a region are assessed. The Grey Prediction Model is then used to predict the number of disasters. Insurance compensation is evaluated based on disaster losses and the number of disasters. Finally, insurance risk is assessed based on premiums and compensation. This article facilitates a more comprehensive investigation and evaluation of a region's disaster scenario, while analyzing strategies to mitigate disaster losses. Furthermore, it assists insurance companies in more effectively assessing underwriting risks in a given area, thereby augmenting their financial gains.

2. Insurance Risk Assessment Model

The insurance companies should assess the risk of the underwriting policies so that they will not go out of business due to too few customers or pay too many claims. However, assessing the risk of underwriting in a given area is a complex issue, and there are many factors that can affect it. To simplify the study, the paper analyzed the benefits and possible loss of underwriting in a area and analyzed the risk according to the benefits and loss.

2.1. Insurance Income and Loss

The income of the insurance depends on the price of the insurance P and the quantity of insurance N.

As the results, the income of the insurance Q_{Income} can be calculated:

$$Q_{Income} = P \times N \tag{1}$$

This relationship between price and quantity is regulated by the market. In general, all else being equal, the supply of a commodity is positively correlated with the price, while the demand is negatively correlated with the price, as shown in Fig 1.

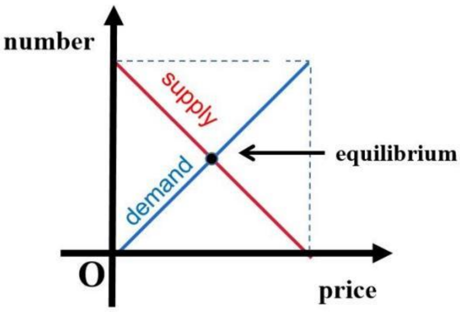

Fig 1: The relationship between supply and demand

Where the two curves intersect determines the equilibrium price in the market. The market will adjusts supply and demand to the equilibrium. Then we can get the price and sales volume.

The relevant studies indicate, the premium charged should be proportional to the frequency of catastrophic loss[5], as shown below:

$$U = k \times f \tag{2}$$

where k is the specific coefficient and f is the probability of catastrophic loss.

When analyze the claims of the underwrite policies, because the scope is large and the time is long, the paper use the mathematical expectation of the claims to assess the loss. Because the damage degree of natural disasters in the same area has little change, and the mathematical expectation of the claims is related to the frequency and loss of disasters. The loss of the underwriter policies is:

$$Q_{Loss} = f \times \mathrm{L} \tag{3}$$

Where L is the loss that caused by one disasters.

Due to the unique climatic and economic characteristics of each region, and the fact that these characteristics do not change rapidly, the impact of natural disasters varies across different areas. The paper use disaster index to assess the damage degree in a region.the disaster index DI is:

$$DI = \sum_{i=1}^{num} w_i x_i \tag{4}$$

Where x_i is the i-th indicator of assess system and w_i is its weight.

In order to explore the relationship between economic aggregate (EA) and disaster losses (DL), we conducted a study on the economic aggregate and disaster losses of 14 European countries in 2021. Since European countries have relatively similar climates and geographical locations, the differences in the degree of disasters are minimal, allowing the study to disregard the influence of the Disaster

Index (DI). The economic aggregate and the disaster losses of these countries in European are shown in Fig 2:

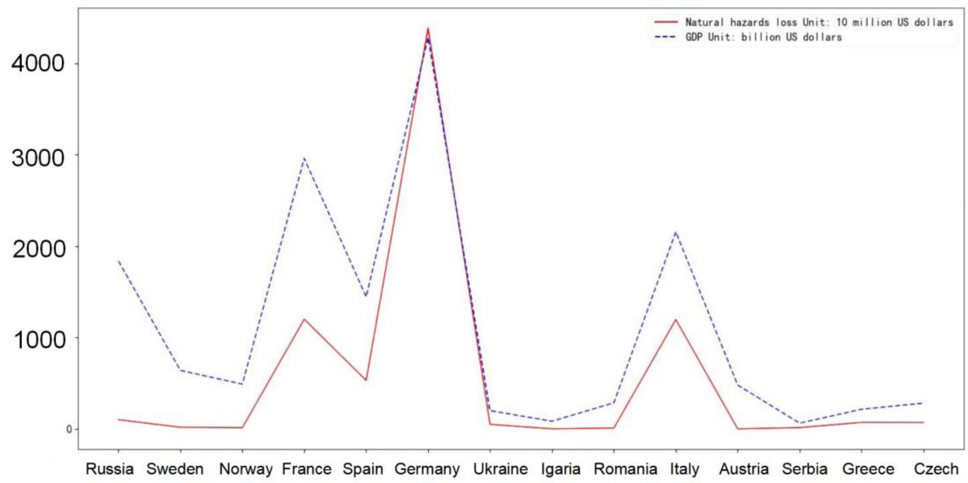

Fig 2: The economic aggregate and disaster losses of 14 European countries in 2021

From the curve, it can be observed that the two curves exhibit a similar trend of variation. And the Pearson correlation coefficient of the EA and DL is 0.88>0.8, that is to say, they exhibit a high positive correlation.

The loss caused by the same degree of natural disasters is positively correlated with the local economic aggregate, the Gross Domestic Production (GDP) can reflect the economic aggregate of a region.

$$\mathrm{L} = \gamma \times GDP \times \sum_{i=1}^{num} w_i x_i \tag{5}$$

Where γ is the adjust coefficient related to insurance rates.

What is worth mentioning is that although there is a positive correlation between losses and the total economic output when the Disaster Index (DI) is the same, countries and regions with higher economic levels may have better disaster prevention measures in place. As a result, their DI may be lower, which lead to potentially thinner losses compared to countries and regions with lower economic levels.

2.2. Disaster Degree Assessment

Referring to the indicator selection principle proposed by Anderson[6], The paper use three First-level indicators include Resilience(RSI), Environment(EN) and Condition(CD) and several Second-level indicators include Emergency Relief Funds (ERF), Disaster Relief Soldiers (DRS), Science and Technology (ST), Education level (ED), Strength of the Structures (SST), Green Coverage Rate (GR), Air Quality (AQ), Land Degradation Rate (LDR), Biodiversity (BI) to assess the disaster degree in a region.

2.2.1 Data Normalization

The above indicators can be classified into two categories based on their impact:benefit attributes and cost attributes.

For benefit attributes, the bigger the better. They can be normalized by the following equation:

$$x_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{6}$$

For cost attributes, the smaller the better. They can be normalized by the following equation:

$$x_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \tag{7}$$

Where x_{ij} represents the j-th data in the i-th group. $\max(x_i)$ and $\min(x_i)$ represents the maximum and the minimum data in i-th group.

2.2.2 Weight Calculation (AHP-EWM)

According to the indicators, the paper use AHP to analyze the issue[7][8], the model is as Fig 3:

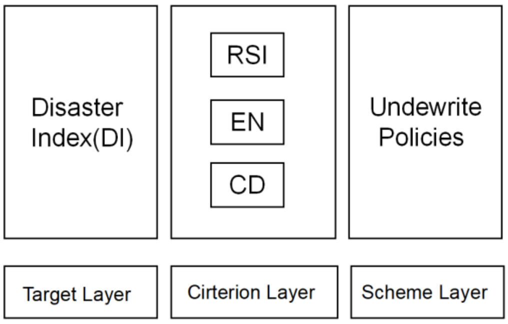

Fig 3: AHP model graph

The Pairwise Comparison Matrix A is:

$$A = \begin{bmatrix} 1 & 3 & \frac{1}{2} \\ \frac{1}{3} & 1 & \frac{1}{7} \\ 2 & 7 & 1 \end{bmatrix} \tag{8}$$

The weights of three First-level indicators are as follows:

$$w = (0.2924, 0.0926, 0.6150), \lambda_{\max} = 3.0026, CR = \frac{CI}{RI} = 0.0025 \tag{9}$$

The consistency is acceptable. The Disaster Index(DI) of a region can be calculated as:

$$DI = 0.2924 \times RSI + 0.0926 \times EN + 0.6150 \times CD \tag{10}$$

Entropy Weight Method (EWM) is used to is used to calculate the weights between primary indicators and secondary indicators[9], as well as between secondary and tertiary indicators.

Calculate the proportion value of the j-th indicators in group i:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{11}$$

Calculate information entropy of each indicators:

$$e_j = -\frac{1}{\ln n} \times \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{12}$$

Calculate the weights of each indicators:

$$w_j = \frac{1 - e_j}{n - \sum_{j=1}^{m} e_j} \tag{13}$$

By using EWM, the weights of indicators are calculated, as shown in Table 1:

Table 1: Weight of indicators of RSI and EN

Level1	Weight of L2/L1	Level2	Weight of L3/L2	Level3	Weight of L3/L1
RSI	0.2274	ERF	1.0000	ERF	0.2274
	0.2295	DRS	1.0000	DRS	0.2295
	0.2314	ED	0.0227	ER	0.0053
			0.9747	GEE	0.2255
			0.0025	TTP	0.0006
	0.1967	ST	0.0075	RDE	0.0015
			0.4070	NRD	0.0801
			0.5855	NPA	0.1152
	0.1150	SST	1.0000	SST	0.1150
EN	0.1495	GR	1.0000	GR	0.1495
	0.4339	AQ	0.3495	CE	0.1516
			0.3432	NC	0.1489
			0.3073	PMC	0.1333
	0.1693	LDR	1.0000	LDR	0.1693
	0.2473	BI	1.0000	BI	0.2473

By using AHP, the weights of indicators are calculated, as shown in Table 2:

Table 2: Weight of indicators of CD

Indicator	Weight	Indicator	Weight
Geological structure	0.2724	Climate change and environmental changes	0.2879
Geological conditions	0.1431	Degree of ecological balance disruption	0.1623
Proximity to plate boundaries	0.5308	Population density of organisms	0.0604
The number of active volcanoes in the vicinity	0.0537	Number of extreme weather days (per year)	0.4894
Precipitation amount and intensity	0.1638	Ocean currents and dynamics	0.5813
Hydrological conditions	0.2973	Coastal topography and coastal development	0.1096
Number of extreme weather days (per year)	0.5389	Distance from the sea	0.3091

The paper uses the following equation to combine the scores of each indicator:

$$Score_x = \sum_{i=1}^{num} \sigma_i y_i \tag{14}$$

Where x is the category of the disaster, num is the number of the indicators , y_i is the score of the i-th indicator and σ is the weights.

Since one or several natural disasters may occur in an area, taking their maximum score:

$$CD = \max\{Score_{GS}, Score_{MH}, Score_B, Score_M\} \tag{15}$$

2.3. Insurance Risk Assessment

The paper have analyzed the income and the loss above, we believe that the risk of the insurance is related by both the income and the loss. The risk of the insurance θ is defined as follows：

$$\theta = \frac{\overline{Q_{loss}}}{\overline{Q_{income}}} \tag{16}$$

Where $\overline{Q}$ is standardized Q.

To assist insurance companies in evaluating whether an region is suitable for underwrite, and based on the ability to pay claims of the insurance companies[10], The paper have made the following standards:

$$\begin{cases} 0 < \theta \le 0.57 \\ 0.57 < \theta \le 0.87 \\ 0.87 < \theta \end{cases} \tag{17}$$

If $0 < \theta \le 0.57$, the risk is acceptable, it is believed that the risk for the insurance companies is small, they can underwrite in the region. If $0.57 < \theta \le 0.87$, the risk is reasonable acceptable, companies should further assess whether to underwrite based on the past conditions and changing trends in the region. If $0.87 < \theta$, the risk is unacceptable, the company is likely to incur losses in this underwriting policy, therefore, they should consider abandoning the underwriting.

2.4. Model Application

Because both Japan and Chile are coastal countries located at plate boundaries, and they are prone to frequent earthquakes and tsunamis, the paper choose Japan and Chile to use the model.

Firstly, collecting the occurrence of major natural disasters in both countries from 2010 to 2023. Based on this, using the grey forecast model[11] to forecast the frequency of natural disasters that may occur in the next phase in both countries. the core formula of GM(1,1) is:

$$x^{(1)}(k+1) = [x^{(1)}(1) - \frac{u}{a}]e^{-ak} + \frac{u}{a} \tag{18}$$

Where u is the development coefficient and a is the grey function.

The frequencies of serious natural disasters we predicted in Japan and Chile are 39 and 24., as shown in Fig 4:

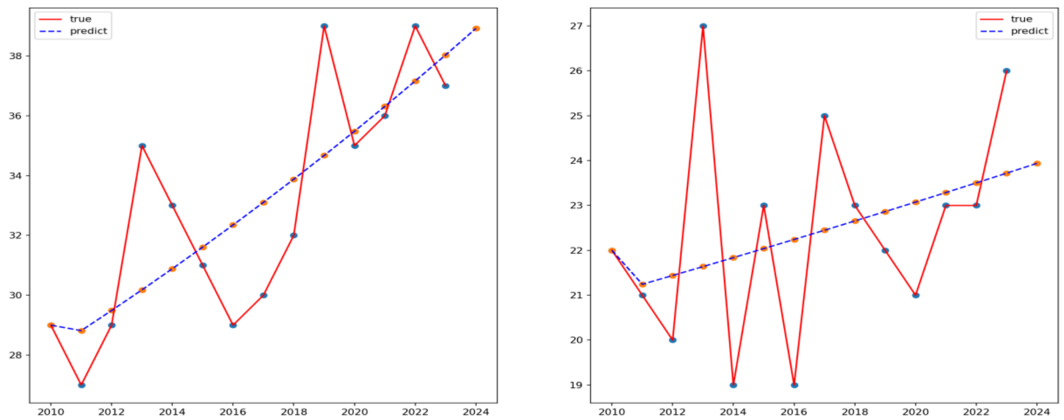

Fig 4: The forecast frequency Japan and Chile

Then, evaluating the Disaster Index (DI) of the two countries based on the collected data, and the DI of Japan and Chile is 63.2513 and 40.1057. Afterwards, calculating the risk values of them, which are 0.71 and 0.88. The risk conditions of both countries are not optimistic, and Japan has a lower risk than Chile. Because Japan has more Emergency Relief Funds and a higher level of disaster prevention education, its resilience to disasters is stronger than that of Chile, resulting in smaller losses from disasters. Additionally, Japan has a significantly larger population than Chile, which leads to higher insurance payouts and lower underwriting risks. Therefore, the paper have proposed the following insurance coverage plans.

For Japan, its risk value belongs to reasonable acceptable risk, it can be further analyzed based on its specific circumstances.Analyze from the loss of the underwrite policies, for areas in Japan that are far from the coast and have less earthquakes, as well as areas where the government's response measures are well-developed, the insurance companies can underwrite them, as they have strong resistance. Analyze from the income of the underwrite policies, the insurance companies can choose the area that have more people to underwrite, because insurance is sold in larger quantities in these densely populated areas, insurance companies can generate higher profits.

For Chile, its risk value belongs to unacceptable risk, underwriting in this country carries high risks. Moreover, Chile has a long and narrow shape, with the entire country being close to the sea. Therefore, the insurance companies is only recommend to underwrite in densely populated areas with good economic development and a favorable environment.

3. Error analysis

When predicting the disaster frequency in Japan and Chile, the paper used the Grey Forecast Model. The paper used the data from Japan between 2010 and 2020 to forecast the data from 2021 to 2023, and then compared it with the actual data to validate the model. As shown in Fig 5.

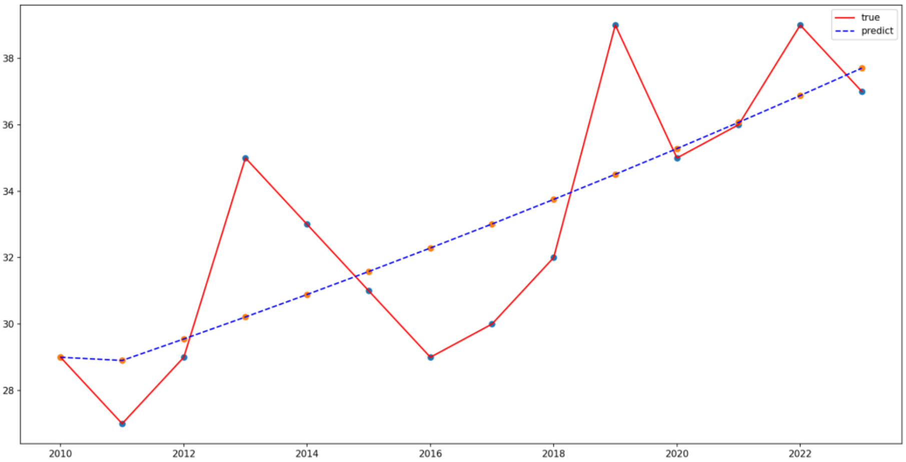

Fig 5: The testing of grey forecast

Compared with the real data, the errors from 2021 to 2023 is 0.2%, 5.4% and 1.9%, these errors are within acceptable limits.

4. Conclusions

The research on natural disasters and the pricing strategies for insurance provide a basis for risk assessment studies, yet traditional methods still have imperfections in assessing risks. This paper establishes a more comprehensive evaluation system using AHP and EWM, it combines both subjective and objective factors, and utilizes grey prediction to forecast disaster occurrences. The evaluation system covers a three-level indicator system, where the secondary indicators encompass various aspects. Subsequently, the paper studied Japan and Chile as examples. The risks underwritten in Japan and Chile are both considerable, with Chilean underwritten risks surpassing those of Japan. Insurance companies should further consider factors such as population, economy, and environment when assessing the regions for underwriting. The results indicate that the risk assessment model possesses good predictability and robustness, with a certain practical application value.

References

[1] Deng Lixian, Yang Fan, Zhao Lanlan. Application of Grey System Theory in Drought and Flood Disaster Prediction[J]. Water Resources Development and Management, 2023, 9(04): 66-70.

[2] Liu Jiankang, Liu Bingqiu, Kuang Wenlong et al. Study on the Acceptable Level of Natural Disaster Risk in Hunan Province[J]. Northwestern Geology, 2024, 57(01): 55-63.

[3] Zou Lihua. Research on Catastrophe Bond Pricing[D]. Yunnan University, 2020.

[4] Shu Longcang, Huang Lei, Chen Huawei et al. Risk Assessment and Zoning of Coastal Seawater Intrusion Disasters in Laizhou City Based on AHP-EWM[J]. Journal of Jilin University (Earth Science Edition), 2023, 53(06): 1864-1879.

[5] Zhou Changfeng. Design and Empirical Study on Pricing Model of Catastrophe Insurance Premium[J]. Journal of Langfang Normal University (Natural Science Edition), 2013, 13(03): 18-21.

[6] Araújo B M ,Anderson P R ,Barbosa M A , et al.Standards for distribution models in biodiversity assessments[J].Science Advances,2019,5(1):eaat4858.

[7] Shen Zhiwan. Risk Study on Agricultural Insurance Investment Projects in Henan Province — Based on AHP-Fuzzy Comprehensive Evaluation Method[J]. Shanxi Agricultural Economics, 2021(16): 188-189.

[8] McKenzie R ,Gala T .Likelihoods of Flood Hazards and Risks Using GIS-Based Analytical Hierarchy Process (AHP)[J].Academic Journal of Environment Earth Science,2023,5(9):

[9] Zhang R ,Tian D ,Wang H , et al.Risk Assessment of Compound Dynamic Disaster Based on AHP-EWM[J].Applied Sciences,2023,13(18):

[10] Tian, L., & Zuo, F. Empirical Study on the Catastrophe Compensation Ability of China's Property Insurance Industry. In Proceedings of the First Academic Annual Conference of the China Insurance Association. School of Economics and Management, Wuhan University, 2009.

[11] Niu Zhuoran. Trend Analysis and Material Distribution Research of Flood Disasters Based on Grey System Theory[D]. Capital University of Economics and Business, 2023.