Making The Best Investment Strategy for Insurance Companies Under The Background of Extreme Weather

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Abstract. In the face of the negative impacts of the frequent occurrence of extreme weather disasters around the world, we have developed natural disaster risk prediction and analysis models for insurance companies to maximize their benefits. This paper first selects six risk indicators, such as flood, cold wave, drought and other disasters, and combines the analytic hierarchy process (AHP) and grey prediction model (GM) to calculate the impact weights of six kinds of natural disasters, and predicts the probability of future occurrence, so as to realize the comprehensive assessment of natural disaster risk. This paper also analyzes the effect of the owner's intention to buy insurance on the insurance strategy through the function model, and solves the optimal insurance strategy through the technique for order preferenceby similarity to ideal solution (TOPSIS) and neural network. We define the ratio of the total profit of natural disaster insurance to the total cost as the decision coefficient K. When K is greater than 35%, the insurance company chooses to write the policy, and when K is greater than 5% and less than 35%, the insurance company chooses to bear the risk. Finally, this paper collected the data of Florida and Kyushu, Japan. Through the insurance model, it calculated that the total profit of natural disaster insurance in Florida was 635.8 million US dollars, while that in Kyushu was -61.51 million US dollars. Therefore, insurance companies should invest in Florida.

Keywords: Extreme Weather, Risk Assessment, Insurance Decisions, AHP, Neural Networks.

1. Introduction

In recent years, the number of extreme weather events has continued to increase globally, and extreme weather events have caused significant adverse social costs [1]. Losses from weather-related disasters are increasing faster than losses from geophysical events such as earthquakes [2]. Insurance, as the main way to reduce the direct economic cost of catastrophic events, reduces the economic impact on the directly affected population by expanding the number of people who share the cost [3]. Following floods in Queensland and Victoria in 2011, many insurance companies failed to cover flood losses on rivers, which caused widespread public discontent and criticism [4]. Therefore, how to better deploy insurance coverage, make risk assessment more flexible, make customers willing to buy insurance, and ensure the profitability of insurance companies is a problem worth exploring.

Clarke, Ben et al. analyzed the impact of climate change on five different types of extreme weather disasters, the impact of each type of recent extreme weather event, and the extent to which the various impacts can be attributed to climate change [5]. Using flood as an example, Rufat, Samuel, Peter J. Robinson et al. assessed the factors related to buying natural disaster insurance and flood protection of houses separately in terms of owners' willingness, and why people can take both measures at the same time [6].

Scholars have conducted a large number of studies on the driving factors of extreme weather to natural disasters, the relationship between natural disaster insurance and disaster reduction measures or other factors that may affect insurance strategies, and comprehensively analyzed the impact of climate change on the occurrence of natural disasters and the factors that affect people's willingness to buy insurance. However, there are few studies on the direct relationship between the probability and severity of natural disasters and the purchase and cost of natural disaster insurance. Based on this,

in the context of serious human and property damage caused by natural disasters, this paper provides a strategy model for insurance companies, starting from six risk indicators, to help them measure insurance costs and benefits, and decide whether they should be insured in a certain area.

2. Construction of Risk Assessment Model

The main sources of data in this paper are shown in Table 1.

Table 1. The data source of this paper.

data name	uniform resource locator
urban land area where elevation is below 5 meters	https://data.worldbank.org/indicator/AG.LND.EL5M.UR.K2?end=2008&start=1990
human and property losses caused by natural disasters and the frequency of disasters	https://ourworldindata.org/natural-disasters#all-charts
demographic data and Environmental and climate change data	https://data.worldbank.org.cn
United States meteorological data	https://www.weather.gov
Meteorological data for Japan	https://www.jma.go.jp/jma/indexe.html
insurance compensation amount and total loss of all kinds of natural disasters	https://www.munichre.com/en.html

2.1. Risk Indicators and Risk Assessment

When evaluating the natural disaster risk of a country, a state, or a city, we will refer to many factors. Considering the frequency and severity of major disasters caused by extreme weather in the world and the universality of the model, we choose floods, droughts, cold waves, high temperature and heat waves, sea level rise, tropical storms, and hurricanes as consideration factors. Next, various factors will be introduced one by one and analyzed quantitatively.

2.1.1. Flood

The severity of the losses caused by the flood is related to the flood grade, population density in the occurrence area, disaster response, and other factors. In this model, we use the flood level to measure. The flood grade can be calculated by Formula (1) [7].

$$N = 12.30\sqrt{\frac{H_{max}-H_0}{\Delta H'_{max}}} + 1 \quad (1)$$

Where N is the flood level, H_{max} is the height of flood peak water level, H_0 is the warning water level and $\Delta H'_{max}$ is the highest water level in a year.

2.1.2. Cold Wave

The cold wave is a serious weather phenomenon. According to the definition standard of cold wave grade in China, from weak to strong, they are cold wave, strong cold wave, and extra-strong cold wave respectively. The division criteria are shown in Table 2 [8].

Table 2. "Cold Wave Grade" and the requirement standard for temperature change.

Standard	Cold wave	Severe cold front	Extremely strong cold wave
the scale of drop in temperature	The drop in 24h ≥ 8℃ The drop in 48h ≥ 10℃ The drop in 72h ≥ 12℃	The drop in 24h ≥ 10℃ The drop in 24h ≥ 12℃ The drop in 24h ≥ 14℃	The drop in 24h ≥ 12℃ The drop in 24h ≥ 14℃ The drop in 24h ≥ 16℃
Thelowest air temperature	Thetemperature ≤ 4℃	Thetemperature ≤ 2℃	Thetemperature ≤ 0℃

2.1.3. Drought

Drought is a climatic phenomenon caused by severe water shortage. This paper adopts the comprehensive meteorological drought index based on PDSI and SPI proposed by Yan Guixia, as shown in formula (2) and Table 3[9].

$$DI = 0.3 * S1 + 0.3 * S2 + 0.4 * \mathrm{P_p} \quad (2)$$

Where $S1$ means one month's standardized precipitation index, $S2$ means three months' standardized precipitation index and $\mathrm{P_p}$ means Palmer drought index.

Table 3. Drought classification by comprehensive meteorological drought index.

Grade of drought and flood	No drought	Mild drought	Moderate drought	severe drought	extreme drought
The range of DI	0.35 < DI	0.25 <DI≤0.35	0.15 < DI≤0.25	0.10 < DI≤0.15	DI≤0.10
frequency of occurrence(%)	69.75	13.41	10.52	3.47	2.84

2.1.4. High-temperature Heat Wave

A heat wave is a phenomenon in which temperatures in the region are significantly higher than normal for a period of time. We choose the classification standard of Chinese heat wave, as shown in formula (3).

$$TI = \begin{cases} 1.8 * T_{max} - 0.55 * (1.8 * T_{max} - 26) * (1 - 0.6) + 32, RH \leq 60\% \\ 1.8 * T_{max} - 0.55 * (1.8 * T_{max} - 26) * (1 - RH) + 32, RH > 60\% \end{cases} \quad (3)$$

Where TI is the heat index, T_{max} is the daily maximum temperature (℃) and RH is the daily average relative humidity (%).

2.1.5. Sea-level Rise

Sea level rise is caused by the thermal expansion of ocean water and the melting of glaciers as a direct result of global warming. To visualize the negative effects of sea level rise, and to take into account the simplicity and applicability of the model, we use urban land area below 5 meters above sea level as a measure.

2.1.6. Tropical Storms and Hurricanes

Tropical storms and hurricanes are different names for tropical cyclones. Their severity depends on the wind speed and wind force at the time of generation, as well as the affected areas and population density. According to China's definition, tropical cyclones are divided into six grades according to the maximum ground wind speed near the center, as shown in Table 4.

Table 4. Classification of tropical cyclones.

name	Stats
Super Typhoon	The maximum average wind speed near the bottom center is ≥51.0 m/s,that is, 16 or above
Severe Typhoon	The maximum average wind speed near the bottom center is 41.5-50.9 m/s,that is, 14-15
Typhoon	The maximum average wind speed near the bottom center is 32.7-41.4 m/s,that is, 12-13
Severe Tropical Storm	The maximum average wind speed near the bottom center is 24.5-32.6 m/s,that is, 10-11
Tropical Storm	The maximum average wind speed near the bottom center is 17.2-24.4 m/s, that is, 8-9
Tropical Depression	The maximum average wind speed near the bottom center is 10.8-17.1 m/s,that is, 6-7

2.2. Natural Disaster Impact Factor

We visualize the data related to natural disasters, use AHP to calculate the damage degree of each natural disaster, classify the natural disaster grades, actively look for the corresponding relationship between disaster probability and risk grade, and determine the influencing factors of disaster risk.The weights of the six disasters are shown in Table 5.

Table 5. The incidence of different types of natural disasters.

Types of disasters	flood	Cold wave	drought	high-temperature heat	sea-level rise	Tropical storm
Influence weight	21.864	11.93	13.813	9.791	18.213	24.390

Then, we use the grey prediction method to predict the probability of natural disasters.

Considering the damage degree and occurrence probability of each natural disaster, we can use Formula (4) to calculate the natural disaster impact factor.

$$C_i = W_i * P_i\ , i\ =\ 1,2,3,4,5,6 \tag{4}$$

Where W_i is the damage degree of the i type natural disaster, P_i is the occurrence probability of the i type natural disaster, and C_i is the influence factor of the i type natural disaster.

3. The Benefits and Costs of Insurance

In the insurance company's total revenue, we take into account the probability of buying insurance, the total number of people in the area, and the average premium. Among them, the purchase probability can be approximated by the owner's willingness to pay. The premiums of different levels are then calculated according to the general insurance pricing rules.In the total cost of an insurance company, we mainly consider two major costs: compensation expenditure and company operation. The main factors affecting the compensation expenditure are the insurance compensation coefficient, the number of insured and the amount of insurance. A company's cost of doing business will be roughly measured by the number of people who buy insurance.

3.1. Owner's Willingness to Pay

Tingting Wu, Zhen Dong et al proposed a model of consumers' willingness to pay insurance for earthquake disasters, and we applied it to extreme weather disasters, as shown in formula (5) [10].

$$WTP = \sum_{i=1}^{n} A_i\, Pa_i \tag{5}$$

Where WTP the willingness to pay is, Pa_i is the amount of payment selection, A_i is the proportion of the amount selected for consumers, n and is the number of options.

Next, we conducted regression analysis on the relevant data of subjective factors and objective factors respectively.

In terms of subjective factors, we conducted regression analysis with the willingness to pay, the personal social and economic information of consumers and the insurance experience as independent variables, and established a regression model as shown in equation (6).

$$Y_Z\ =\ \alpha_1 T_1 + \alpha_2 T_2 + \alpha_3 T_3 + \alpha_4 T_4 + \alpha_5 T_5 + \alpha_6 T_6 + \alpha_7 T_7 + \varepsilon_1 \tag{6}$$

Where the consumer's willingness to pay for natural disaster insurance in terms of subjective factors, $Y_Z, T_1,\ T_2,\ T_3, T_4,\ T_5, T_6, T_7$ respectively represent gender, age, region, personal income, recommendation from relatives and friends, insurance experience and insurance impression,$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7$ are seven regression coefficients, ε_1 is indicating residual items.

In terms of objective factors, the risk degree of natural disasters can be calculated by multiplying the weight of natural disasters with the disaster level, and the regression equation is established as shown in Formula (7).

$$Y_K = \beta_1 N_1 + \beta_2 N_2 + \beta_3 N_3 + \beta_4 N_4 + \beta_5 N_5 + \beta_6 N_6 + \varepsilon_2 \quad (7)$$

Where Y_K express consumers' willingness to pay for natural disaster insurance in terms of objective factors.the new variables$N_1, N_2, N_3, N_4, N_5, N_6$ represent the risk degree of flood, drought, cold wave, high temperature heat wave, sea level rise, tropical storm and hurricane respectively, and $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ are six regression coefficients, ε_2 is indicating the residual term.

3.2. Insurance Amount and Premium

We use γ_k to represent the premium of Grade k, σ_{k} to the premium of Grade k, and M_k to the insurance coverage of Grade k. In the model, we assume that the insurance period is one year, the predetermined interest rate is 3.5%, and the compensation events are concentrated in the middle of a year. Then we bring in a predetermined interest rate of 1.75% for calculation. Accordingly, the average annual insurance premium can be expressed as formula (8).

$$\sigma_{\mathrm{k}} = M_k * \sum P_i / [(1 - \gamma_k) * 1.75], \mathrm{k} = 1,2,3,4 \quad (8)$$

3.3. Profit Model of Insurance Company

Before considering the total profit of insurance companies, we also need to supplement the average insurance premium, insurance compensation coefficient, and company operating costs. We use the random forest method to calculate the weight of different grades of insurance. The first grade is 46.655%, the second grade is 31.504%, the third grade is 16.897%, and the fourth grade is 4.944%. The average insurance premium m is calculated as shown in Formula (9).

$$\mathrm{m} = \sum_{\mathrm{k}=1}^{4} \sigma_{\mathrm{k}} * \varphi_{\mathrm{K}} \quad (9)$$

When determining the insurance payout coefficient, we determine the relationship between the payout coefficient b and the insurance level and the disaster loss based on the actual case. The specific compensation coefficient is shown in Table 6.

Table 6. Determination of insurance compensation coefficient.

the insured amount (Thousand $) \ the degree of damage	<15%	15%~50%	50%~80%	80%~100%
50	0	30%	50%	80%
300	0	40%	60%	85%
1,000	10%	50%	65%	90%
3,000	30%	60%	70%	95%

In the solution of the company's operating cost, we use the number of insured people to approximate the company's size, thus simulating the actual operating cost C_1. We use C_0 to represent the fixed cost and r to represent the cost coefficient, so the operating cost of the company is shown in Formula (10).

$$\mathrm{C}_1 = \mathrm{r} * W\mathrm{TP} * \mathrm{Num} + \mathrm{C}_0 \quad (10)$$

The compensation expenditure C_2 is shown in Formula (11).

$$\mathrm{C}_2 = W\mathrm{TP} * \mathrm{Num} * \mathrm{b} * \mathrm{Wa} \quad (11)$$

Where $W\mathrm{TP}$ the willingness to pay is, Num is the total population of the area, b is the compensation coefficient, and Wa is the total loss caused by the disaster.

Finally, we get the profit model of the insurance company as shown in Formula (12).

$$\omega = WTP * \text{Num} * m - C_2 - C_1 \quad (12)$$

Where ωthe total profit and m is is the average insurance premium.

3.4. Optimal Insurance Strategy

When we only use the profit to decide whether the insurance company should set up natural disaster insurance in a certain area, we use the ratio of total profit to total cost to judge. The decision coefficient k is defined as shown in Formula (13).

$$k = \frac{\omega}{C_2 + C_1} \quad (13)$$

When the decision coefficient k<5%, for the purpose of profit, the insurance company will not set up natural disaster insurance in this area; When the decision coefficient k>35%, the insurance company underwrites the policy; When the decision coefficient is 5%<k<35%, the insurance company chooses to take risks. We can minimize the losses caused by natural disasters and improve the decision-making coefficient by taking pre-disaster protection measures and strengthening publicity.

3.5. Model Test Result

In the case study of the insurance model, we selected the typical hurricane affected Florida in the United States and the flood storm affected Kyushu in Japan. In these two cases, we will show the huge losses caused by natural disasters to the economic development of the two regions, calculate the total profit of natural disaster insurance through the profit model of insurance companies, and analyze the rationality of the results.

3.5.1. Florida, USA

Florida is a frequent place for hurricanes, which have caused serious casualties and property losses. In September 2018, Hurricane Dennis hit southern Florida, killing at least 25 people. Hurricane Andrew, which hit Florida in 1992, caused the insurance industry to pay out $11 billion. The economic losses caused by natural disasters in the United States as a percentage of GDP are shown in Figure 1.

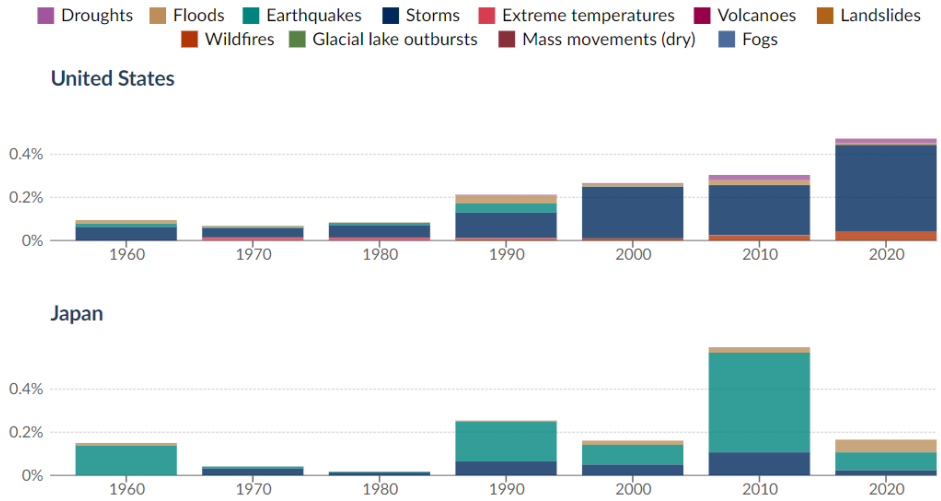

Figure 1. Economic damages from disasters as a share of GDP, United States and Japan.

We conducted a random forest classification of Florida's natural disaster insurance purchases over the past 40 years, setting annual natural disaster insurance quotas of 50,000, 300,000, 1 million and 3 million. According to the analytic hierarchy process, among the total number of people who buy natural disaster insurance, the proportion of these four kinds of insurance is 46.655%, 31.504%, 16.897% and 4.944% respectively.

The benefits and costs of natural disaster insurance can be calculated by combining the willingness to buy insurance, the extent and amount of damage caused by the disaster, and the number of people who buy insurance. As can be seen from equation (12), the total profit of Florida natural disaster insurance for insurance companies is 635.8 million US dollars.

In the model, we calculated that Florida's insurance payouts due to natural disasters were $505.8 million. In fact, although Florida has frequented natural disasters, due to the optimistic local economic situation, people's willingness to buy insurance is generally high, and the net income of insurance companies is high. In addition, the local infrastructure is perfect, the disaster resistance is good, and the insurance payout is relatively small. Given their relationship to operating costs, it is reasonable to explain that Florida natural disaster insurance brings a high total profit to insurance companies.

3.5.2. Kyushu Island, Japan

Heavy rains, floods and storms occurred frequently on the Japanese island of Kyushu, causing serious casualties and property losses. In 2016, the island of Kyushu was hit by heavy rains and floods that killed at least 22 people. In 2017, Typhoon Jeppe killed at least 11 people. The proportion of economic losses caused by various major disasters to GDP is shown in Figure 1.

Similar to the Florida analysis, we set the average annual insurance coverage for natural disasters in Japan at $50,000, $100,000, $500,000, and $1 million, respectively. According to the analytic hierarchy process, among the total number of people who buy natural disaster insurance, the proportions of the four kinds of insurance are 44.843%, 37.453%, 14.551% and 3.153%, respectively. According to Formula (12), it can be calculated that the insured loss of natural disasters on Kyushu Island is USD 0.9444542 billion. Because the region's total population is only about half the population of Florida, relatively few people have purchased insurance. In addition, floods, hurricanes, earthquakes and other natural disasters occur frequently in the region, and the insurance payout is relatively high. Therefore, it is reasonable that Kyushu's natural disaster insurance will be in the red.

4. Conclusions

Aiming at the problem of profit maximization, this paper establishes a natural disaster insurance model for insurance companies, evaluates six risk elements, analyzes the cost benefits of insurance companies, and then makes strategy optimization. Finally, it can judge when insurance companies should write insurance policies and when they should choose risks. This paper analyzes the data of the Florida region and Kyushu region, and finally calculates that the total profit of natural disaster insurance in Florida is 635.8 million US dollars, while the total profit in Kyushu is -61.51 million US dollars, so the insurance company should invest in Florida.

The model in this paper is considered comprehensive and realistic, as it is built upon comprehensive literature consultation to understand the modeling object. It simplifies design ideas, increasing analysis efficiency by idealizing complex problems. The model is innovative, analyzing internal relations to present an original framework. However, it has limitations due to the complexity and relevance of analyzed objects, such as not thoroughly analyzing government influence or reinsurance impact on profits. Additionally, there may be a tradeoff in factor importance due to limitations in problem perception, and more risk indicators could be considered.

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