Exploration of Property Insurance Benefits in Extreme Weather

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Abstract. In recent years, the increasing frequency of extreme weather events has highlighted the insurance industry's dilemma - the profitability of insurance companies and the capacity of policyholders to bear the burden are in crisis. Therefore, seeking the development of property insurance in this environment is crucial. This paper establishes a Risk Assessment Model with a four-level index system, including four main indicators: natural, economic, social, and engineering defense, to assess the disaster risk and losses of a specific area. Subsequently, a Rate-Adjusted Break-Even Analysis Model is established and coupled with the Risk Assessment Model to facilitate practical insurance decision-making. By establishing this highly flexible and practical assessment system, precise indicators can be selected for evaluation based on the varying impacts of natural disasters in different regions. This will enable more accurate decision-making for local catastrophic insurance coverage. Consequently, it allows local residents to obtain better post-disaster relief protection against natural calamities, while businesses can also benefit from substantial reconstruction returns.

Keywords: Catastrophic Insurance, Risk Assessment Model, Rate-Adjusted Break-Even Analysis Model.

1. Introduction

Catastrophe risk management is one of the global challenges now. Catastrophes can result in significant human casualties and property losses. Traditional relief measures appear inadequate compared to the high losses caused by catastrophes, and the ability to disperse catastrophe risks is clearly insufficient.

Catastrophe insurance refers to the protection against natural disasters such as typhoons, tsunamis, earthquakes and severe storm surges, which are uncontrollable events that can result in substantial property losses and endanger human life, thereby posing significant socio-economic risks to countries. It serves as a mechanism for transferring the risks associated with these events, addressing the limitations of traditional disaster relief measures. By leveraging financial instruments, catastrophe insurance serves the social governance system, embodies the political and populist nature of insurance, and plays an important role as an economic shock absorber and social stabilizer in national economic and social development, disaster prevention, mitigation, and relief [1]. Therefore, countries around the world have long been actively exploring the strengthening of risk management through catastrophe insurance to ensure social security and stability [2]. However, the development of catastrophe insurance has been extremely slow, with weak public awareness and a lack of appropriate pricing evaluation systems and institutional guarantees, resulting in low insurance coverage and insufficient willingness to insure, among other developmental issues.

From the current exploration of catastrophe insurance, it mainly focuses on floods and earthquakes, while the development and research of other types of catastrophe insurance (such as blizzards, frost, mudslides, and other disasters) are still in their infancy [3]. In addition, due to the diverse and complex nature of catastrophes in different natural environments and economic conditions, catastrophe insurance pricing requires a highly localized natural disaster risk assessment model to ensure reasonable insurance pricing and promote the development of catastrophe risk management and actual insurance coverage. This article incorporates multiple types of risks into the evaluation system, establishing the evaluation system based on local data on natural, economic, social, and engineering defense levels, improving the multi-hazard assessment system to serve the pricing system of catastrophe insurance, making the pricing system more personalized and universally applicable.

2. Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations

Symbol	Description	Unit
R	Risk coefficient of natural disasters for a certain plot	-
R_{nature}	Hazard coefficient of natural disasters for a certain plot	-
R_{human}	Damage coefficient of natural disasters for a certain plot	-
$R_{engineering}$	Engineering defense coefficient of a certain plot	-
C	Insurance company operating cost	$
C_f	Insurance basic cost	$
C_v	Average unit cost per insurance sold	$
r_c	Insurance claim ratio	-
P	Average selling price per insurance	$
Q_{sum}	Total insurance coverage	-
C_a	The claim amount for each insurance	$
m_i	The amount to be compensated in the i^{th} year	$
n_i	The number of insurance claims to be paid in the i^{th} year	-
j	Stable annual investment rate of insurance companies	-

3. The Fundamental of Risk Assessment Model

The impact of extreme weather on a region is multifaceted, covering various aspects including natural, economic, and social dimensions. Considering these, this paper has comprehensively considered the hazardous nature of disasters, their impact on the economy and society, and the variability in engineering defense capabilities to establish a Risk Assessment Model. This model provides a comprehensive assessment of the natural hazard and economic-social damage caused by disasters.

3.1. Natural Hazard Assessment

In the same area, different natural disasters often occur, and sometimes these disasters even happen concurrently. Therefore, drawing inspiration from the principles of remote sensing interpretation overlay [4], this paper constructs multiple single disaster risk layers for the same area and overlays them.

The hazard level of natural disasters can be considered from two dimensions: the hazard weight and the hazard level of each type of disaster.

(1) Hazard weight: The proportion of the impact of each type of natural disaster on the plot. As only natural factors are considered, the area of vulnerable areas can be evaluated based on natural conditions such as topography and climate, and then obtain the proportion of influence.

(2) Hazard level of single disaster type: The destructive power of each type of natural disaster. As only natural factors are considered, the researchers can predict based on historical data of the intensity and frequency of each type of natural disaster occurring in the plot, and obtain a comprehensive assessment based on historical and predicted data.

Based on this, the assessment formula for the hazard coefficient of natural disasters is as follows:

$$R_{nature}=\begin{cases}\frac{\sum_{i=1}^{n}\alpha_i Z_i}{an}, & \frac{\sum_{i=1}^{n}\alpha_i Z_i}{n}<a \\ 1, & \frac{\sum_{i=1}^{n}\alpha_i Z_i}{n}\ge a\end{cases} \tag{1}$$

In the formula, n is the number of layers in the map (i.e., the quantity of natural disasters being assessed), α represents the hazard weight, Z_i represents the hazard level of single disaster type. a makes the value of R_{nature} controlled in $[0,1]$.

3.2. Destructiveness Assessment

Destructiveness assessment is an evaluation of the extent of damage caused by various disasters to the economy and society of a particular region. Natural disasters have a significant impact on the economy and society. The destruction of urban infrastructure, damage to agricultural land, and casualties are all potential consequences [5]. Due to significant differences in the economic and social development of different regions, the destructiveness assessment is divided into two parts: economic damage assessment and social damage assessment.

3.2.1 Economic Damage Assessment

The losses caused by natural disasters are relative to humans. Therefore, this paper decides to consider the relationship between economic development and the losses caused by extreme weather.

(1) Economic damage weight: it refers to the impact of each type of natural disaster on the economy of a specific area. Since economic factors are only being considered, researchers can measure it by assessing the destruction caused to buildings and agricultural land by each type of natural disaster [6].

(2) Economic damage extent of a single disaster type: it refers to the intensity of economic destruction caused by each type of natural disaster in a specific area. This can be evaluated by selecting relevant indicators related to the economy, industries, etc.

Based on this, the formula for calculating the economic damage assessment value is as follows:

$$r_{economy}=\begin{cases}\frac{\sum_{j=1}^{n}\beta_j e_j}{bn}, & \frac{\sum_{j=1}^{n}\beta_j e_j}{n}<b \\ 1, & \frac{\sum_{j=1}^{n}\beta_j e_j}{n}\ge b\end{cases} \tag{2}$$

In the formula, n is the quantity of natural disasters being assessed, β_j represents the economic damage weight, e_j represents the economic damage extent of a single disaster type. b makes the value of $r_{economy}$ controlled in $[0,1]$.

3.2.2 Social Damage Assessment

Each year, many people lose their lives in major natural disasters. Typically, disasters of the same intensity can cause greater damage in areas with higher population density. Additionally, regions with higher levels of education should have better disaster prevention and mitigation awareness, as well as emergency evacuation knowledge. This plays an important role in reducing casualties and minimizing social damage.

Similarly, the social damage caused by natural disasters can be considered from two dimensions: the social damage weight of each type of natural disaster and the social damage extent of a single type of disaster.

(1) Social damage weight: The magnitude of the impact of each natural disaster on the local society. Since social factors are only being considered, researchers can measure it based on the number of casualties.

(2) Social damage extent of a single disaster type: The level of destruction caused by each natural disaster on the local society. Since social factors are only being considered, researchers can choose indicators such as urbanization level, education level, etc.

Based on this, the formula for social damage assessment is as follows:

$$r_{society} = \begin{cases} \dfrac{\sum_{j=1}^{n} \gamma_j r_j}{cn}, \dfrac{\sum_{j=1}^{n} \gamma_j r_j}{n} < c \\ 1, \dfrac{\sum_{j=1}^{n} \gamma_j r_j}{n} \geq c \end{cases} \tag{3}$$

In the formula, n is the quantity of natural disasters being assessed, γ_j represents the social damage weight, γ_j represents the social damage extent of a single disaster type. c makes the value of $r_{society}$ controlled in $[0,1]$.

3.2.3 Overall Calculation of Destructiveness Assessment

On one hand, regions with higher levels of economic development and population density tend to experience greater damage [7]. On the other hand, economically developed areas generally have stronger disaster resilience, which partially offsets the increase in disaster losses. Therefore, the relationship between damage extent and economy/social factors should exhibit a non-linear pattern, with rapid initial growth followed by a gradual slow-down.

Based on this viewpoint and empirical evidence, the damage coefficient for natural disasters is often modeled as a non-linear function.

$$R_{human} = \left(\frac{r_{economy} + r_{society}}{2} \right)^{\frac{1}{2}} \tag{4}$$

3.3. Assessment of Engineering Defense Capabilities

Engineering defense plays a significant supporting role in current disaster prevention and mitigation efforts. Structures such as high-strength buildings, flood control dams, and storm protection facilities can reduce the direct loss of life and property caused by natural disasters [8]. Additionally, equipment like weather radars and flood monitoring systems can enhance early warning and monitoring capabilities for natural disasters, enabling timely detection and prediction of disasters and effectively mitigating their impact.

Regions with higher levels of economic development tend to prioritize and invest more in the construction of engineering defense capabilities, as they possess greater resources and technological capabilities to address the challenges posed by natural disasters [9].

Engineering defense capabilities can be considered from two dimensions: the economic damage weight of various natural disasters and the degree of economic damage.

(1) Disaster resistance weight: It reflects the importance of various disaster resistance indicators in engineering defense.

(2) Single-hazard economic damage degree: The disaster resistance intensity of various disaster resistance indicators, such as the strength of building materials and structures.

Based on this, the formula for the engineering defense coefficient is as follows:

$$R_{engineering} = \begin{cases} \dfrac{\sum_{k=1}^{m} \rho_k y_k}{d}, \sum_{k=1}^{m} \rho_k y_k < d \\ 1, \sum_{k=1}^{m} \rho_k y_k \geq d \end{cases} \tag{5}$$

In the formula, m represents the number of selected indicators that reflect the disaster resistance capabilities of a building. ρ_k represents the disaster resistance weight, which signifies the importance of each indicator in engineering defense. y_k represents the disaster resistance indicator value. d is a factor that controls the value of $P_{engineering}$ within [0, 1].

Unlike hazard and vulnerability, stronger engineering defense capabilities correspond to greater resistance against extreme weather events and the disasters they cause. Therefore, risk should be inversely proportional to engineering defense capabilities [10]. In view of this, the risk assessment model is optimized as follows:

$$R' = \frac{R_{nature} \times R_{human}}{R_{engineering}} \tag{6}$$

4. The Fundamental of Rate-Adjusted Break-Even Analysis Model

After obtaining the Risk Assessment Model for natural disasters, a Rate-Adjusted Break-Even Analysis Model is established to help people decide whether to underwrite policies in an area that has a rising number of extreme weather events. Our model is based on:

(1) Break-Even Analysis model: It refers to calculate the break-even point by analyzing the relationship between a company's sales volume, costs, prices, and profits, and to guide the management practice of the company.

(2) Core Principle for Sustainable Insurance Operations: The principle of profitability exceeding losses, simply yet essentially.

(3) Accurate assessment of natural disaster risk: The hazard coefficient derived from a multitude of indicators exhibits both predictive and directional qualities due to its comprehensive evaluation of historical and forecasted data.

4.1. The Establishment of the Basic Model

The first step is to calculate the insurance company operating cost, which do not include payouts. These costs are associated with the daily operations and management of the insurance company and are not directly related to insurance claims.

$$C = C_f + C_v Q_{sum} \tag{7}$$

The second step is to calculate the total claim amount. Calculate it on an annual basis. By establishing a recursive relationship, the formula can be derived for the total claim amount as follows:

$$R_{sum} = \sum_{i=1}^{t} m_i = \sum_{i=0}^{t-1} C_a Q_{sum} r_c (1 - r_c)^i \tag{8}$$

The profits of the insurance company are determined by the premiums collected, minus the claim amounts, further subtracted by the operational costs of the insurance company. Additionally, this calculation is linked to the prevailing interest rates.

Here this paper believes that the amount m_i that needs to be claimed in year i has generated interest rate income $m_i\left[(1+j)^i - 1\right]$ for the insurance company, and the amount m_i after compensation will not generate interest rate income. At the same time, a function $f(PQ_{sum} - C - R_{sum})$ is introduced to judge that at that time $PQ_{sum} - C - R_{sum} \geq 0$, this part of the amount can generate stable income.

On the contrary $PQ_{sum} - C - R_{sum} < 0$, this paper only defines it as a temporary imbalance of revenue and expenditure, without considering that the insurance company will borrow and maintain.

To sum up, the formula for the income of insurance companies is as follow:

$$
\begin{aligned}
W_{sum} &= \sum_{i=1}^{t} m_i \left[(1+j)^{i+1} - 1\right] r_c (1-r_c)^i + (1+j)^{f(PQ_{sum}-C-R_{sum})}\left(PQ_{sum} - C - R_{sum}\right) \\
&= \sum_{i=0}^{t-1} Q_{sum} C_a \left[(1+j)^{i+1} - 1\right] r_c (1-r_c)^i + (1+j)^{f(PQ_{sum}-C-R_{sum})}\left(PQ_{sum} - C - R_{sum}\right)
\end{aligned} \tag{9}
$$

In this formula, $f(PQ_{sum} - C - R_{sum}) = \begin{cases} t, PQ_{sum} - C - R_{sum} \geq 0 \\ 0, PQ_{sum} - C - R_{sum} < 0 \end{cases}$

4.2. Further Discussion: Resilience

Resilience refers to the ability to cope with sudden meteorological disaster risks that are significantly beyond our reasonable range of prediction [11].

To make our model more flexible and strengthen the response to small probability events with significant enhancement of sudden meteorological disasters (completely beyond the reasonable fluctuation of prediction) [12], this paper considers that the claim rate in the m+1 year suddenly increases to $kr_c (k \leq 2)$ in this *t* year, and the claim rate in other years remains unchanged. Based on this, the previous model is modified to obtain the total claim amount R_{sum} and income W_{sum} as follows:

$$
R_{sum} = \sum_{i=0}^{\tau-1} C_a Q_{sum} r_c (1-r_c)^i + Q_{sum} C_a k r_c (1-r_c)^{\tau} + \sum_{i=\tau}^{t-2} Q_{sum} C_a r_c (1-kr_c)(1-r_c)^i \tag{10}
$$

$$
\begin{aligned}
W_{sum} &= \sum_{i=0}^{\tau-1} C_a Q_{sum} r_c (1-r_c)^i [(1+j)^{i+1} - 1] + Q_{sum} k r_c (1-r_c)^{\tau} C_a [(1+j)^{\tau+1} - 1] \\
&+ \sum_{i=\tau}^{t-2} C_a Q_{sum} r_c (1-kr_c)(1-r_c)^i [(1+j)^{i+2} - 1] + (1+j)^{f(PQ_{sum}-C-R_{sum})}\left(PQ_{sum} - C - R_{sum}\right)
\end{aligned} \tag{11}
$$

In the formula, the definition of $f(PQ_{sum} - C - R_{sum})$ is the same as above.

Take the second, fourth, sixth, eighth, and tenth years respectively, and the fluctuation degree is the largest (k=2). Through c++ operation, the relationship between claim ratio, insurance basic cost, total insurance coverage and W_{sum} can be obtained.

Table 2. The reference values of some parameters

Symbol	Reference value	Unit
Insurance basic cost	1000000000	$
Insurance claim ratio	0.0029	-
Average selling price per insurance	3000	$
Total insurance coverage	1000000	$
The claim amount for each insurance	500000	$
Amount of years	10	year
Average unit cost per insurance sold	300	$

The reference values of some parameters used above are shown in Table 2. Among them, the benchmark value of the claim ratio is updated by c++ operation. Focus on the analysis of the claim ratio, whose relationship with the income W_{sum} is showed in Figure 1.

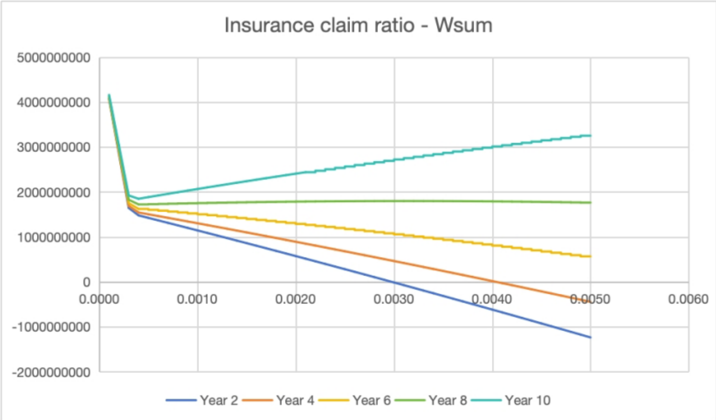

Figure 1. The relationship between claim ratio and income

It can be seen that as time goes on, the operation of insurance companies will be more stable and their profits will be more considerable.

According to the calculation results, insurance is recommended when the loss coverage rate is 0.0029, and risk insurance is recommended when the loss coverage rate is 0.0034, and the risk coefficient is 0.4833 and 0.5667 respectively.

5. RA-RABEA Model: Risk Coefficient and Claim Ratio

Integrate Risk Assessment Model with Rate-Adjusted Break-Even Analysis Model, and a RA-RABEA Model is established. In the above model, the claim ratio represents the proportion of the number of claims to the total number of insured persons. In the insurance industry, "expected incidence" usually refers to the probability that a certain risk or event will occur in a specific period of time in the future, which is the same as the concept of risk coefficient in the RA model. Therefore, the relationship between risk coefficient and claim ratio is as follow:

$$R = \frac{C_a r_c}{P} \tag{12}$$

6. Conclusion

This paper links the risk assessment of natural disasters with decision-making regarding catastrophe insurance, providing guidance for enterprise insurance decisions and optimizing the pricing model of catastrophe insurance. It offers a targeted and locally prominent model for furthering the development of catastrophe insurance, characterized by high flexibility and elasticity, and possessing considerable practical value. Precisely selecting indicators for assessment based on the varying impact of natural disasters in different regions will lead to more accurate decisions in local catastrophe insurance coverage. It is expected that the insurance module in the model will be enhanced using modern algorithms and actuarial models to provide more precise pricing guidance.

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