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Evaluation of Expected Insurance Returns in Extreme Weather Based on CRITIC and Generalized Extreme Value Distribution Methods

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Abstract. The frequency of extreme weather events has become a powerful catalyst for huge economic losses. Payouts for natural disasters have increased significantly, leading to a rapid rise in premium rates, and the phenomenon poses a serious challenge to the profitability of insurance companies. In order to specifically study the impact of extreme weather on the calculation of the expected profit that an insurance company can make from underwriting a policy for a specific landmass, and thus to assess the applicability of insurance in a certain region, this paper, based on the data of economic losses due to extreme weather events in five continents from the EM-DAT database. Using the CRiteria Importance Through Intercriteria Correlation (CRITIC) method and the Generalized Extreme Value (GEV) distribution method, we build a model for assessing the expected profit from insurance and verify the applicability of the model through sensitivity analysis. Finally, we provide a reference for insurance companies' underwriting strategies, a probabilistic assessment for property owners to insure their properties, and a reference suggestion for communities to enhance their extreme weather risk tolerance.

Keywords: Extreme weather; insurance; CRITIC method; Generalized Extreme Value (GEV) distribution method.

1. Introduction

With global warming and changes in the natural climate, the frequency of extreme weather is increasing. Natural disasters such as storms, floods, droughts, and heat waves may have wide-ranging economic impacts. Guo Xingxu(2018)[1] pointed out that extreme weather events are natural phenomena in which weather conditions such as temperature and precipitation are substantially higher or lower than the normal average of previous years during a certain period of time in a certain region and cause greater damage to human production, social, economic and other activities. Extreme weather events are often accompanied by catastrophic damage, such as floods, hurricanes or wildfires caused by high temperatures. These events typically cause extensive property damage and personal injury, which can result in a large number of insurance claims. Insurance companies may have to adjust rates to cope with higher claims pressure, and premiums for insurance coverage rise rapidly, making the increase in extreme weather a severe test of insurers‘ profitability, as well as a test of property owners' affordability. Reassessment and designation of insurance models in light of changes in the frequency and intensity of natural disasters is therefore imminent. And specific quantification of the impact of extreme weather can help insurers develop more effective risk management strategies to reduce losses. Katherine R. H. Wagner(2022) [2] mentions re-evaluating insurance models in light of the changing frequency and intensity of natural disasters is necessary. Jesse D. Goure-vitch(2023)[3] et al. emphasize the difference between current property values and their adjusted values in their article, as well as when considering the risk of future climate change-induced flooding. Guo Xingxu(2018)[1] describes the impact of extreme weather events on agricultural production in Hubei in terms of extreme high temperatures, extreme low temperatures, extreme precipitation, and extreme droughts; Wei Hualin (2010)[4] and others argue that food production is closely related to weather and climatic conditions The frequent occurrence of extreme weather events has seriously affected agricultural production, and agricultural insurance, as an important financial tool to cope with weather disasters and guarantee food security, has been given worldwide Attaches great importance to. Tian Zhenhua,Wu Xuemin (2022) [5] and others believe that there are many difficulties in the operation of agricultural insurance in extreme weather, from the point of view of reducing risk management, the implementation of the concept of prevention is more important than compensation is not sufficient, from the point of view of the supply side of the insurance, the supply of insurance products urgently need to be innovated. Kati Kraehnert (2021) [6] and others believe that although the insurance has had a positive impact, but to a large extent , losses due to extreme weather events are not insured, not only in the Global South but also in developed economies; risk pools are highly constrained and insurers must charge higher premiums to cover residual risks. Domestic and international scholars have differed in their focus, but none have examined how the insurance industry should choose to underwrite. Therefore, in this paper, we use the CRITIC method and the Generalized Extreme Value (GEV) distribution method to construct the insurance expected return model, and make a clear delineation of the four risk-return zones to carry out, and at the same time, we combine the Generalized Extreme Value (GEV) distribution method to carry out the modelling can effectively overcome the limitation that the CRITIC method is unable to analyze the frequency. Finally, we develop underwriting strategies for the insurer in different regions and provide property owners with a probability assessment of insurance coverage. By testing this model with sensitivity analysis, we demonstrate that the model is feasible and provides property owners with guidance to influence insurers' decisions.

2. Introduction to the methodology

2.1. CRITIC method

The CRITIC (CRiteria Importance Through Intercriteria Correlation) method is an objective approach to assigning weights based on the intensity of comparison and conflicts among indicators. Talip Arsu(2022)[7] considers the weight of importance of the criteria reflects the amount of information on each of them on the decision matrix. This method relies solely on the objective attributes of the data. The intensity of comparison is measured by standard deviation, with a higher standard deviation indicating significant differences between indicators and thus higher weights. Indicator conflicts are represented by the correlation coefficient; a stronger positive correlation indicates smaller conflicts and thus lower weights. When the standard deviation remains constant, smaller conflicts among indicators result in lower weights, while greater conflicts lead to higher weights. Additionally, a higher degree of positive correlation between two indicators (with a correlation coefficient closer to one) indicates smaller conflicts, reflecting greater consistency in the information about the merits of evaluation options.

The steps for the CRITIC method are as follows:

(1) Indicator Variability

Expressed in the form of standard deviation, the standard deviation is used in the CRITIC method to indicate the fluctuation of the differences in the internal values of the indicators, the larger the standard deviation indicates that the greater the difference in the value of the indicator, the more information can be projected, the stronger the evaluation strength of the indicator itself, and the more weight should be assigned to the indicator.

$$\begin{cases} \bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \\ S_j = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{ij}-\bar{x}_j\right)^2}{n-1}} \end{cases} \tag{1}$$

where:

S_j Standard deviation of the j-th criterion, indicating its variability.

(2) Conflictiveness of indicators

Expressed in the form of correlation coefficients, correlation coefficients are used to express the correlation between indicators; the stronger the correlation with other indicators, the less the indicator conflicts with other indicators, reflecting more of the same information, and the more repetitive the content of the evaluations that can be embodied, which to a certain extent weakens the strength of the evaluation of the indicator, and should be reduced by assigning fewer weights to the indicator.

$$R_j = \sum_{i=1}^{p} (1 - r_{ij}) \tag{2}$$

where:

r_{ij} is the correlation coefficient.

R_{ij} is the conflict measure, which is the sum of uniqueness scores across all criteria.

(3) Volume of Information

The larger C_j is, the greater the role of the j-th evaluation indicator in the whole evaluation indicator system, the more weight should be assigned to it.

$$C_j = S_{j\sum_{i=1}^{p}(1-r_{ij})} = S_j \times R_j \tag{3}$$

where:

C_j denotes the composite measure of criterion j, combining variability and uniqueness.

S_j denotes the standard deviation of criterion, indicating variability.

(4)Objective Weighting

So the severity of the disaster W_j of the j-th indicator is:

$$W_j = \frac{C_j}{\sum_{j=1}^{p} C_j} \tag{4}$$

2.2. The Generalized Extreme Value (GEV) distribution method

The Generalized Extreme Value (GEV) distribution method is a statistical model employed for the analysis and prediction of extreme event magnitudes (both maximum and minimum values). This model is particularly significant in the analysis of extreme events within the domains of hydrology, meteorology, and environmental science, facilitating the estimation of probability distributions for extreme weather phenomena, such as peak temperatures, maximum precipitation levels, and extreme wind velocities.

$$H(x; \mu, \sigma, \xi) = \exp\left\{-\left(1 + \xi\frac{x-\mu}{\sigma}\right)^{-\frac{1}{\xi}}\right\}, 1 + \xi\frac{x-\mu}{\sigma} > 0 \tag{5}$$

in this equation:

x_i represents a set of independent and identically distributed (i.i.d.) random variables, all of which conform to the same distribution function F(x).μ denotes the location parameter. This parameter determines the center or location of the distribution. ε is the scale parameter. ε >0 ensures the scale or spread of the distribution. x denotes the shape parameter. This is the key parameter that determines the tail properties and overall shape of the distribution. The value of x affects the frequency and intensity of extreme events:

When ε =0, it denotes “Gumbel Distribution”.

$$H_1(x;\mu,\sigma) = e^{-e^{-\frac{x-\mu}{\sigma}}}, -\infty < x < +\infty \tag{6}$$

When ε >0, let $\alpha = \frac{1}{\varepsilon}$, it denotes "Frechet Distribution."

$$H_2(x;\mu,\sigma,\alpha) = \begin{cases} 0 & x \leqslant \mu, \\ e^{-\left(\frac{x-\mu}{\sigma}\right)^{-\alpha}} & x > \mu, \end{cases} \quad \alpha > 0 \tag{7}$$

When ε <0, let $\alpha = \frac{-1}{\varepsilon}$, it denotes "Weibull Distribution."

$$H_3(x;\mu,\sigma,\alpha) = \begin{cases} e^{-\left(-\frac{x-\mu}{\sigma}\right)^{\sigma}} & x \leqslant \mu, \\ 1 & x > \mu, \end{cases} \quad \alpha > 0 \tag{8}$$

3. Modelling and solving

3.1. Modelling

We incorporate the investment returns of an insurance company from underwriting policies in the specified region into the consideration of comprehensive returns. When the region is impacted by extreme weather conditions, the amount lost due to insurance payouts constitutes the payment costs of the insurance company. Tanya Fiedler (2021)[8]mentions that assessment of future climate risk requires knowledge of how the climate will change on time and spatial scales that vary between business entities. In light of the above, we define the expected return function as:

$$EQ = (1 + r)^n - B \cdot (1 - (1 - \beta)^n) \tag{9}$$

In this equation, EQ denotes the expected return function. r is the annual interest rate for bank deposits. n represents years of insurance. B signifies the payout multiplier. β indicates the loss ratio.

3.1.1. Definition of $\boldsymbol{\beta}$—the Loss Ratio

The loss ratio β is comprised of two components: the severity s of damage caused by extreme weather events in a particular region, as assessed by the CRITIC method, and the probability p of extreme weather occurrences in the region, calculated based on the Generalized Extreme Value (GEV) distribution method. These two elements collectively constitute the loss ratio within the revenue model, which is closely linked to the payout multiplier B within the insurance model. The specific calculation process is shown in Figure 1.

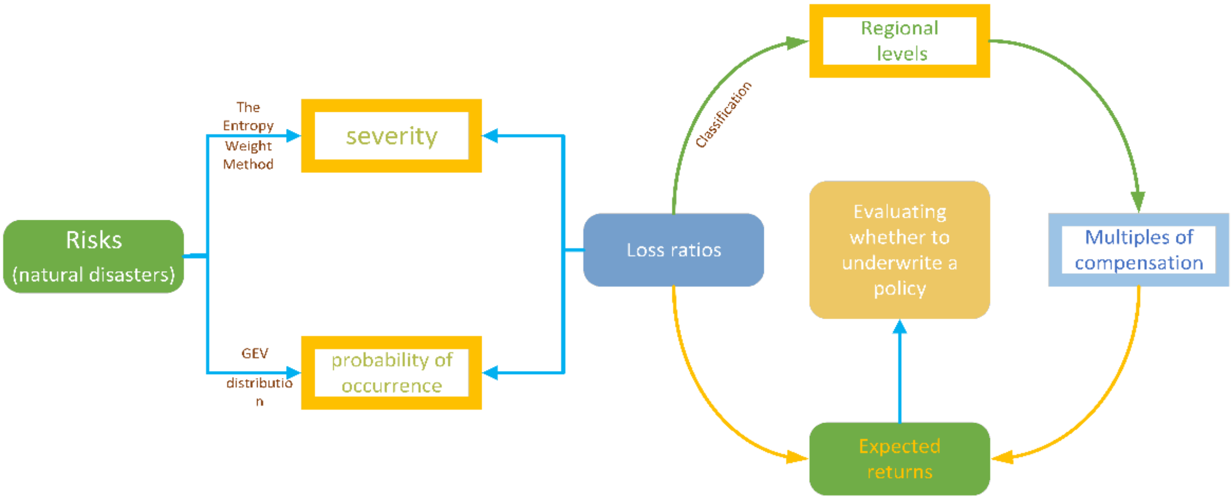

Figure 1. CGE Model

3.1.2. Definition of *B*—Payout Multiplier

The Payout Multiplier B is a critical influencing factor, According to Mathews Adera Gonga(2017)[9], the lower the loss ratio, the better the financial performance and the lower the total claim costs earned. High-risk products are often associated with higher payout ratios, reflecting an increased likelihood of claims. Such a risk-based pricing strategy ensures that the premiums collected are commensurate with the risks assumed, thereby safeguarding the financial stability of insurance companies.

Varying payout ratios allow insurers to price their products more accurately according to the specific risk characteristics of each product. Consequently, this assists in attracting the appropriate customer segments and mitigates adverse selection, where individuals more likely to file a claim are more inclined to purchase insurance.

The value of B will change as the situation changes.

The delineation of this process is depicted in the diagram below.

Initial Rapid Growth: When the population size is much smaller than the carrying capacity K, the population grows rapidly, approaching the intrinsic growth rate r.

Stable Equilibrium: As the population size approaches the carrying capacity K, the growth rate gradually decreases, and the population stabilizes around a value determined by K.

Nonlinear Growth: Unlike exponential growth, which is linear, logistic growth exhibits a nonlinear growth rate, which depends on the current population size relative to the carrying capacity.

3.2. Model Solving

We have calculated the expected returns under varying destruction rates β, insurance coverage ratios B, and the number of years of insurance protection n, as illustrated in Figure 2.

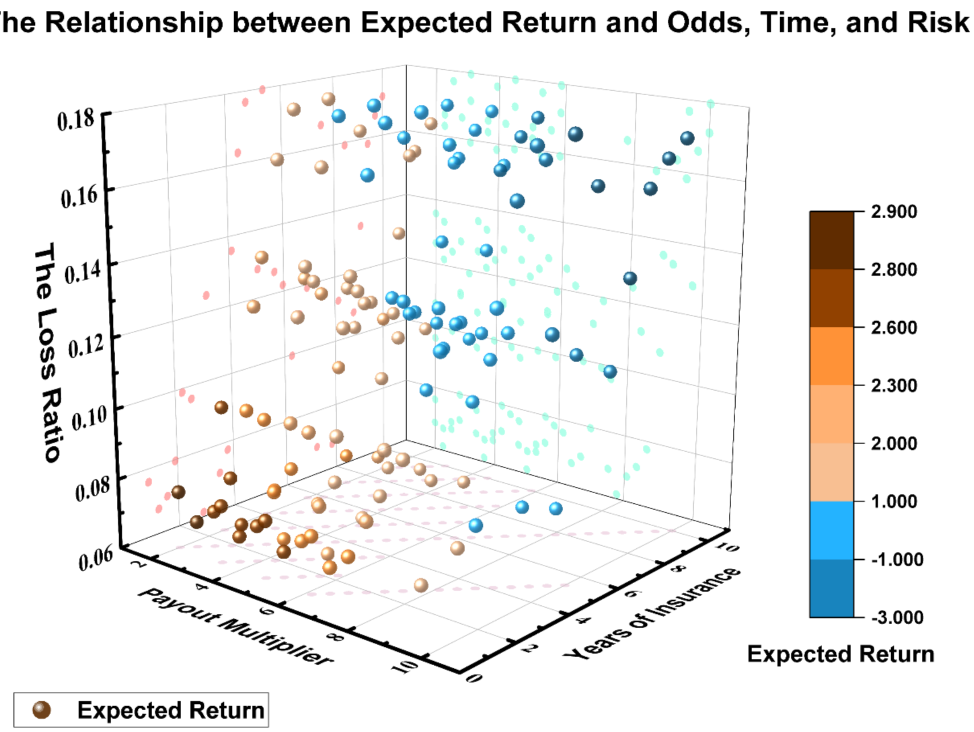

Figure 2. Expected Return

Based on the results, this paper delineates four different profit zones, which are high profit zone (0 ~ 0.08), low profit zone (0.08 ~ 0.12), low loss zone (0.12 ~ 0.14) and high loss zone (0.14 ~ 1), and the specific conclusions are as follows:

(i) When the loss ratio is 0 ~ 0.08, the payout multiplier is 2 times, and the insurance period is within 2 years, the insurance company will get the highest expected return, which is 2.6 times ~ 2.9 times of the principal.

(ii) When the loss ratio is 0.08~0.12, the payout multiple is 2~6 times, and the insurance period is 2~10 years, the insurance company will get the higher profit, which is 2~2.6 times of the principal.

(iii) When the loss ratio is 0.12 to 0.14, the payout multiple is 2 to 8 times, and the insurance period is 2 to 8 years, the insurance company will have a lower profit, 1 to 2 times the principal.

(iv) When the loss ratio is 0.14~1, the payout multiple is 6~10 times, and the insurance period is 6~10 years, the insurance company will have a loss.

3.2.1. Model Validation

In this part of the model we used 3 regions (Austria, Costa Rica, the Cape Hatteras Lighthouse) for the calculations. Austria and Costa Rica were used to demonstrate the model and the Cape Hatteras Lighthouse was used to validate the model.

We obtained from the EM-DAT database the economic losses of five continents due to extreme weather events such as Storm, Flood, Wildfire, Drought, High Temperature, Cold Wave, etc. and calculated the Damage Severity of each damage category using the CRITIC method. Based on this, we calculated the Damage Severity for each category of damage using the CRITIC method, the results of which are shown in Figure 3.

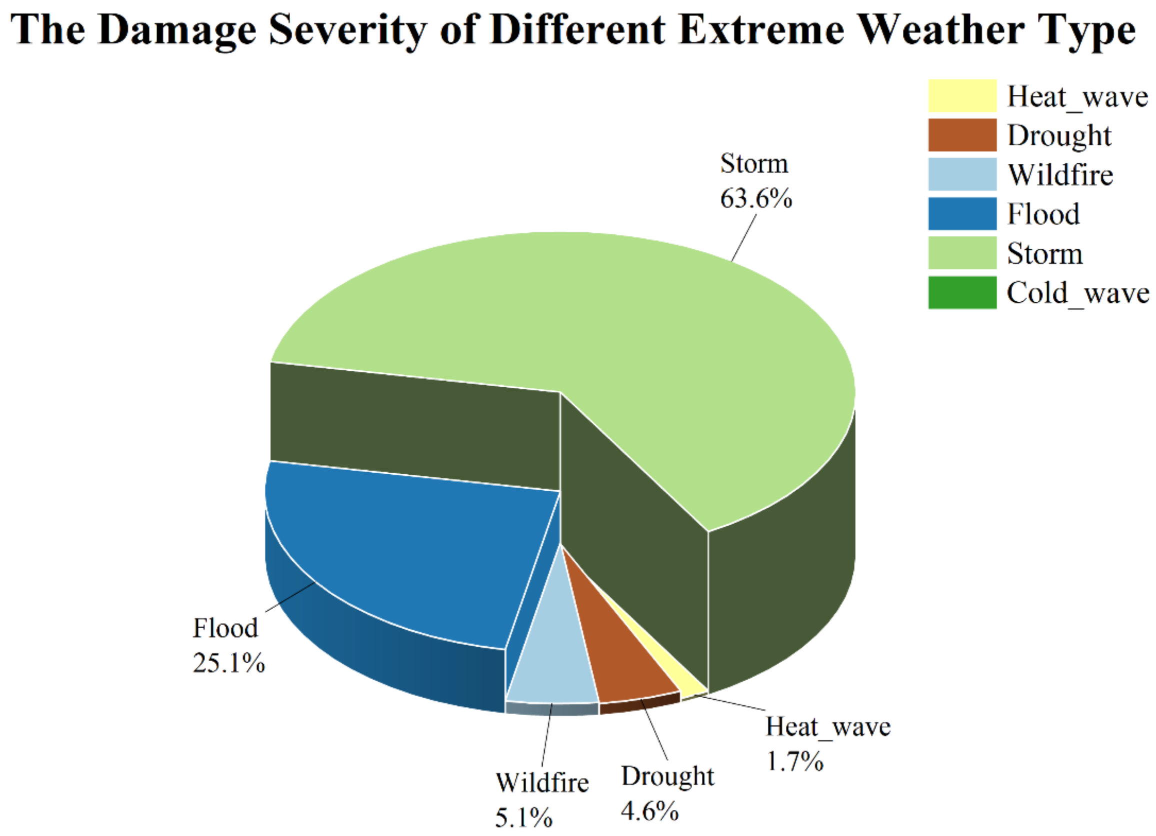

Figure 3. Chart of changes in returns for the four risk zones

From the graph we can observe that 62.64% of the economic losses are caused by storms, 24.66% of the economic losses are caused by floods and the remaining 12.7% of the economic losses are caused by the rest of the four weather extremes. The results of the calculations are similar to the findings of the study by Rebecca Newman et al. and their findings.

We selected the metrics of temperature, humidity, relative humidity, and wind speed for our calculations. Due to the variability between the metrics, we used the Gumbel distribution to calculate the likelihood of extremes in the metrics of temperature and humidity, and the Fréchet distribution to calculate the likelihood of extremes in relative humidity and wind speed. The partially notated results of the calculations for both distributions are shown in Figure 4:

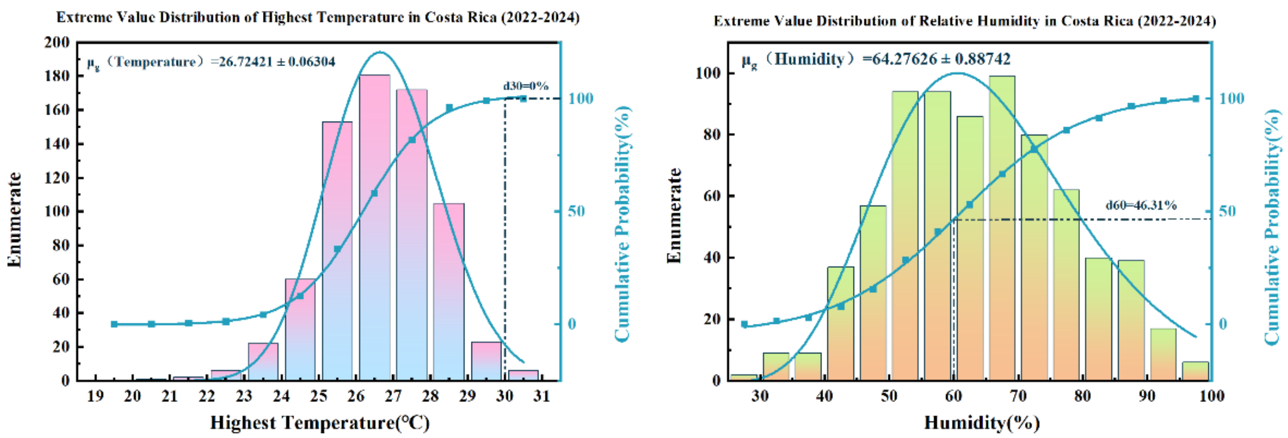

Figure 4. Chart of changes in returns for the four risk zones

After obtaining the corresponding results from the above analysis, we multiply the Damage Severity of extreme weather with the probability of occurrence to obtain the loss ratios for the six types of extreme weather. the specific results are shown in Figure 5:

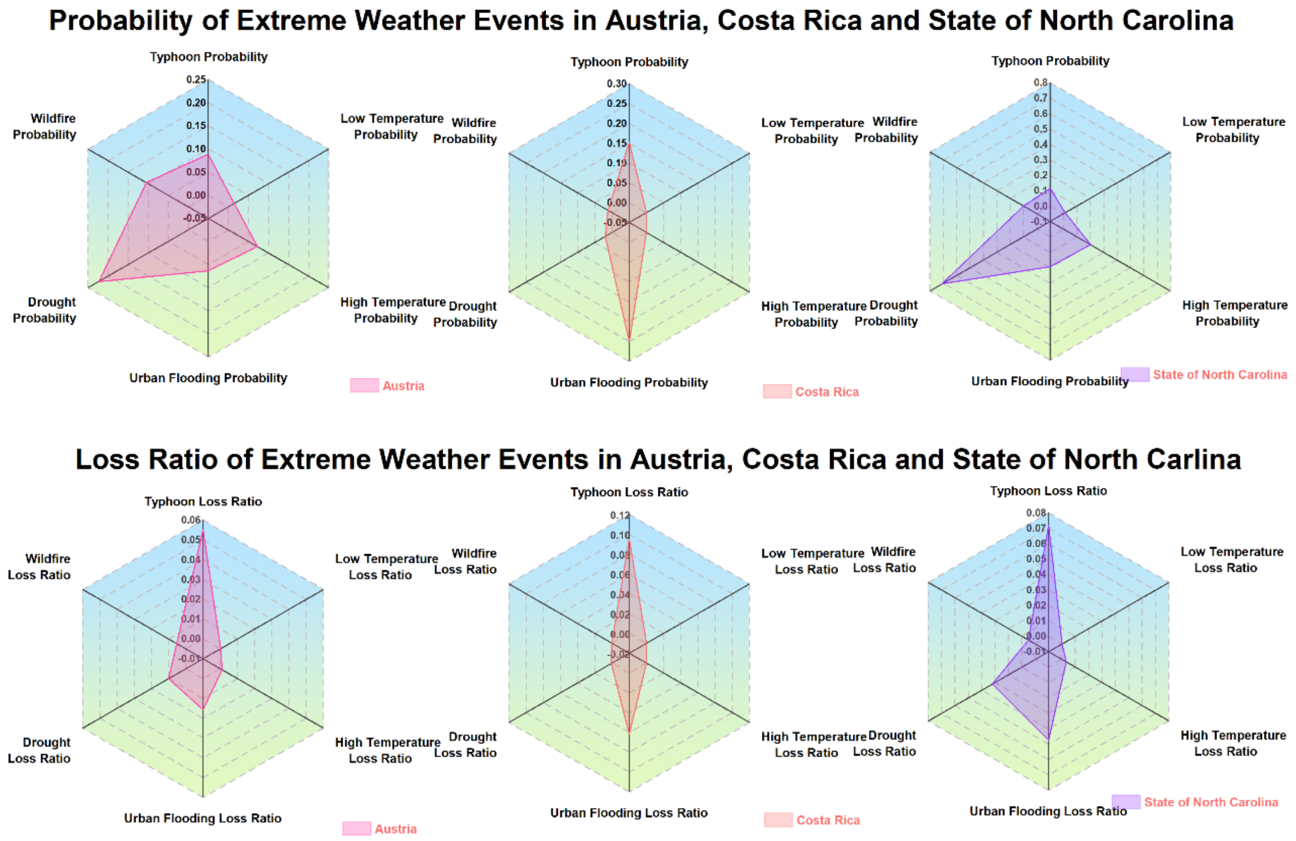

Figure 5. Radar Maps of Different Locations

3.2.2. Sensitivity Analysis

We have set the insurance coverage period, denoted as 'n', to one year. Subsequently, we varied the Loss Ratio, and the results are presented in Figure 6 :

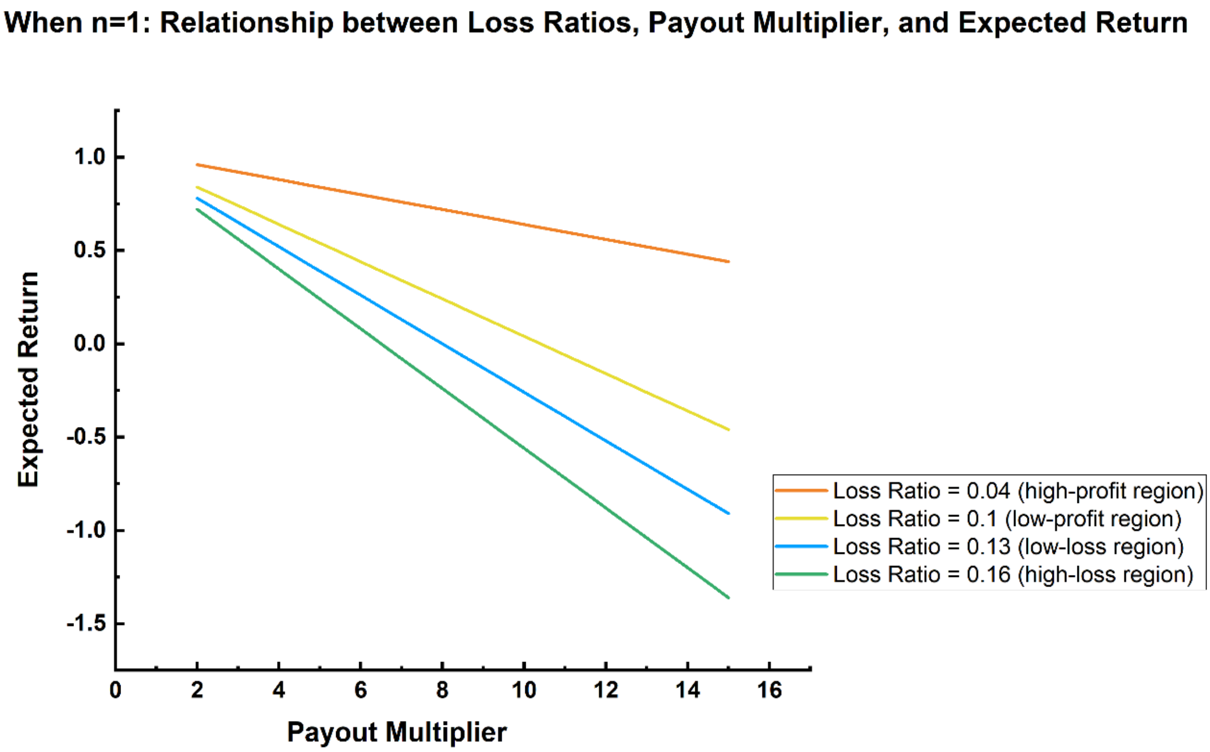

Figure 6. sensitivity analysis

From the graphical analysis we can see that the expected output is getting larger and larger with B for different Loss Ratio when the odds are increasing. It can be seen that the model is more sensitive to Loss Ratio β. However, when we look at the probability distribution and the probability of making up the distribution in Figure 6, we find that the important component of β, the probability of occurrence p, will be too large or too small due to the selection of the threshold value of the Generalized Extreme Value (GEV) distribution method and its large changes. However, it is fortunate that we have been able to determine a reasonable threshold value for the Generalized Extreme Value (GEV) distribution method through our previous research experience, so that the probability of occurrence p can be controlled within a very small range of variation. Based on this, we can also obtain a more stable Loss Ratio β. In summary, we can consider that our model is robust with a reasonable choice of threshold.

3.3. Recommendation

3.3.1. For the insurance companies

According to the article of Yan Su(2019) [10], risk differential rate is one of the core systems of the deposit insurance system, i.e., the insured institutions are classified according to the risk level and different rate levels are determined, with higher rates applying to the insured institutions with higher risks and lower rates applying to the insured institutions with lower risks, so our suggestions for insurance companies are as follows:

For high profit areas, insurance companies should increase their underwriting efforts in the area in order to make considerable profits. They may consider lowering the rates appropriately to attract more business and at the same time introduce more competitive insurance products to expand their market share.

For low-profit areas, insurance companies should carefully assess risks and returns to avoid losses due to excessively low rates. Rates can be raised appropriately to control the scale of business in order to maintain a reasonable level of profit.

For low loss areas, insurance companies should prudently assess whether to underwrite the area. Risk diversification by way of co-insurance or reinsurance can be considered, such as setting an underwriting limit and transferring the excess to co-insurance or reinsurance in order to control the risk of loss.

For high loss areas, if they are assessed to be buildings of very high cultural or historical value, the insurer may consider underwriting the area if the government provides subsidies, but it needs to ensure that the cost after subsidy is lower than the revenue, and risk diversification measures, such as co-insurance or reinsurance, should be adopted. If the government does not provide subsidy or the cost is still higher than the revenue after subsidy, the insurance company should carefully consider whether to underwrite the polic.

3.3.2. For the Owners

Insurance serves two main purposes for homeowners: protecting transferable and non-transferable assets. Companies are more willing to insure assets with high or low profitability, regardless of transferability. However, they’re hesitant to insure high-loss or low-loss assets due to the risk involved.

For non-transferable, high-loss assets, owners can improve risk resistance and extend insurance coverage periods to show insurability. Budget constraints might require adjusting the insurance amount to increase the insurer’s willingness to underwrite.

For transferable assets, additional strategies include relocating them to lower-risk areas. This increases the insurer’s willingness to provide coverage and gives owners more insurance options. And for homeowners who can't get insurance, Howard Kunreuther(2016)[11] suggests that they can be be given vouchers tied to loans for investing in loss reduction measures.

3.3.3. For the Property Developers

Real estate developers are most concerned about attracting more homeowners to buy their homes. Safety is definitely one of the most important factors that homeowners consider when moving in. Accordingly, building in low-risk areas (classified by insurance companies as high-profit and low-profit areas) is an effective measure to attract more homeowners. If a property developer can only build in high-risk areas due to certain constraints, it can reduce the risk of construction by improving the design of the building plan and using building materials that are more resistant to extreme weather, thereby attracting more homeowners.

3.3.4. For the community

Compared to property developers, communities usually have already formed a certain scale of owners, and the location of the community can not be easily changed. Therefore, it is more important for the community to assume the fixed risk and enhance the stickiness of the owners. Firstly, the community can work with property developers to increase the risk tolerance of the owners in the community. In addition, it is also important to protect and promote the community's totems and values to enhance the owners' sense of spiritual identity and attraction to the outside world.

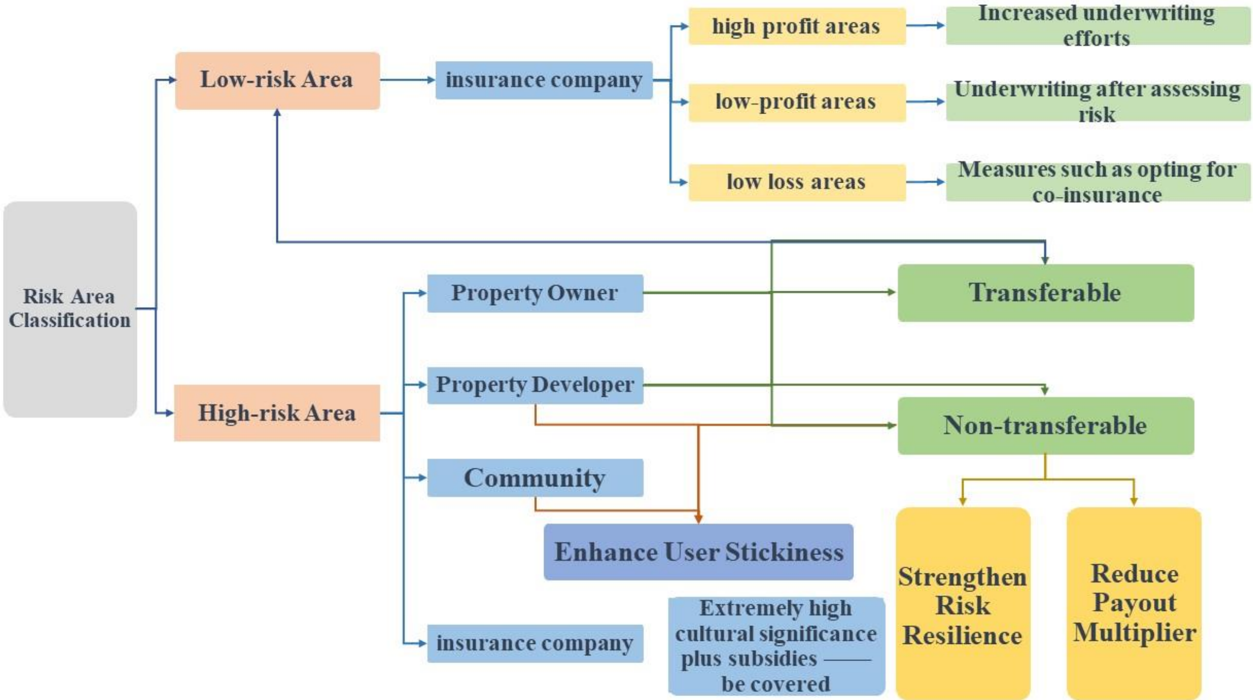

Figure 7. Chart of changes in returns for the four risk zones

4. Conclusions

In order to specifically study the impact of extreme weather on the calculation of the expected profit that an insurance company would make from underwriting a policy for a specific landmark, and thus assess the applicability of insurance in a certain region, this paper analyses the critical values (wind speed, temperature, precipitation, relative humidity) defined by extreme weather events such as typhoon, low temperature, high temperature, urban flooding, drought and flooding, based on Google as well as EM-DAT databases and the five continents' data of economic loss due to extreme weather events Data on economic losses caused by extreme weather events were used to measure the likelihood of extreme weather occurring in the target area, and the severity of damage for each damage category was calculated using the CRITIC method; the product of the two was then used as the loss ratio for the six extreme weather types, which was finally combined with the payout multiplier, thus modelling the assessment of the expected return on insurance. The results of the model under different scenarios were obtained through the changes of the payout multiplier and the insurance years and loss rates, and accordingly, four different profit zones were delineated, namely, high profit zone (0 ~ 0.08), low profit zone (0.08 ~ 0.12), low loss zone (0.12 ~ 0.14) and high loss zone (0.14 ~ 1), and the specific conclusions are as follows:

(1) When the loss ratio is 0 ~ 0.08, the payout multiplier is 2 times, and the insurance period is within 2 years, the insurance company will get the highest expected return of 2.6 times ~ 2.9 times the principal amount.

(2) When the loss ratio is 0.08~0.12, the payout multiplier is 2~6 times, and the insurance period is 2~10 years, the insurance company will get the higher profit, which is 2~2.6 times of the principal.

(3) When the loss ratio is 0.12~0.14, the payout multiplier is 2~8 times, and the insurance period is 2~8 years, the insurance company will have lower profit, 1~2 times of the principal.

(4) When the loss ratio is 0.14~1, the payout multiplier is 6~10 times, and the insurance period is 6~10 years, the insurance company will have a loss.

We conclude by recommending that insurance companies make underwriting strategy decisions based on the four risk zones; provide property owners with a probabilistic assessment of insuring their property and recommendations for reducing their property losses; and provide a reference for communities to enhance the extreme weather risk tolerance of their area.

References

[1] GUO Xingxu. Research on the impact of extreme weather events on agricultural production in Hubei[J]. Rural Economy and Science and Technology,2018,29(13):197-198

[2] Wagner, K.R.H. Designing insurance for climate change. Nat. Clim. Chang. 12, 1070–1072 (2022).

[3] Gourevitch, J.D., Kousky, C., Liao, Y.(. et al. Unpriced climate risk and the potential consequences of overvaluation in US housing markets. Nat. Clim. Chang. 13, 250–257 (2023).

[4] WEI Hualin,WU Lianqiang. Weather index insurance and sustainable development of agricultural insurance[J]. Finance and Trade Economics,2010,(03):5-12+136.

[5] TIAN Zhenhua,WU Xuemin,QIU Jian. Difficulties and countermeasures of agricultural insurance operation under extreme weather[J]. Banker,2022,(02):110-112+7.

[6] Kati K ,Daniel O ,Christian H , et al. Insurance Against Extreme Weather Events: An Overview[J].Review of Economics,2021,72(2):71-95.

[7] Arsu, Talip. Assessment of Macroeconomic Performances and Human Development Levels of BRICS and MINT Countries Using CRITIC and COPRAS Methods[J]. A Refereed Monthly International Journal of Management, 2022, 14(04): 1-19.

[8] Fiedler, T., Pitman, A.J., Mackenzie, K. et al. Business risk and the emergence of climate analytics. Nat. Clim. Chang. 11, 87–94 (2021).

[9] Gonga, Mathews Adera. Determinants of Financial Performance of Insurance Firms: a Survey of Selected Insurance Firms in Nairobi County[J]. Strategic Journal of Business & Change Management, 2017.

[10] Yan Su. Research on risk differential rates of deposit insurance system in China[J]. Journal of Shanghai University of International Business and Economics,2019,26(01):97-107.

[11] Kunreuther H ,Lyster R .The role of public and private insurance in reducing losses from extreme weather events and disasters[J].Asia Pacific Journal of Environmental Law,2016,19(1):29-54.