Property Insurance Model in Growing Extreme Weather Events Summary

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Abstract. In the context of global climate change and frequent natural disasters, the protection and insurance decisions for cultural heritage have become increasingly important. In this paper, we first assessed the conservation value of historic buildings, used the McKinsey Logic Tree Model to select four indicators of cultural, historical, economic, and community significance, and computed the weights of each indicator through Analytic Hierarchy Process (AHP), and Entropy weight method to provide a decision-making model for community leaders to determine whether a particular building should be conserved. Additionally, a decision-making model for insurance companies was constructed, to calculate the combined weights of the disaster risk indicators, applying K-means clustering to categorize the risks, and predicting the probability of an insurance company's insolvency through a multivariate linear regression equation to help determine the insurance decision and the amount to be underwritten. Further optimization of the model considered key variables such as the probability of insolvency, underwriting risk, and the number of potential insured, and the insurance model was adjusted and optimized to assess whether, where, and how to establish an insurance mechanism. Finally, the Asakusa Temple in Japan is used as a case study to analyze its conservation value and corresponding underwriting measures.

Keywords: Analytic Hierarchy Process (AHP), Entropy Weight Method, Natural Disaster Insurance, Multiple Linear Regression, Multi-objective Decision.

1. Introduction

With the intensification of global climate change and the increasing frequency and intensity of extreme weather events, the deterioration of the climate environment has become a global problem that cannot be ignored. Such changes have had a profound impact on many aspects of human society, especially in the protection of cultural heritage and insurance decisions. Cultural heritage not only carries historical and cultural values, but also has irreplaceable significance in economic and social fields. However, the vulnerability of cultural heritage increases significantly under extreme weather conditions, facing the risk of damage, erosion or even complete disappearance. Therefore, how to reasonably protect cultural heritage in this context and how insurance companies can make appropriate insurance decisions has become a topic of great concern.

There has been some prior scholarly research in this area. Ravankhah M provides a comprehensive risk management guide to help cultural heritage managers develop intervention plans. The guide draws on risk assessment methodologies from public health and insurance, and emphasizes the long-term protection and management of cultural heritage in the context of climate change. The problem is that the implementation of existing policies and strategies can be complex at the operational level. De Masi Francesco in 2021 explores insurance options for Italian churches in the face of natural disasters, emphasizing the special needs of cultural heritage protection. The author explores how risks can be reduced through insurance decisions. However, the article also points out that many studies focus on physical restoration and neglect climate adaptation strategies. Kotova Lola examines how regional climate models can be used to assess the impact of climate change on cultural heritage. The article focuses on the impacts of climate variables such as humidity and wind speed on heritage conservation, pointing out the shortcomings of existing models in terms of geographic resolution, which make it difficult to accurately predict specific impacts on individual cultural sites Cacciotti Riccardo et al. 2024 present a methodology for assessing the vulnerability of cultural heritage to extreme climate change. Its innovative approach combines the vulnerability of cultural heritage with the impacts of climate change. However, the model's applicability in complex situations remains limited. This is due to insufficient consideration of multiple interacting climate hazards. Elnaggar Abdelrazek presents a case study on the impacts of climate change on Mediterranean museum collections. The study demonstrates how climate-induced flooding and rising humidity cause irreversible damage to museum buildings and collections.While the study provides some protective measures, the challenge is to cope with more frequent and extreme climate events in the future.

Our study introduces several innovations based on the existing literature. First, we not only discuss cultural heritage from the single perspective of whether it should be protected, but also from the perspective of insurance companies, focusing on the risk-benefit balance behind cultural heritage protection. Second, we introduce the impact of extreme weather on insurance decisions, especially when cultural heritage is threatened by a high frequency of natural disasters, and how insurance companies can make rational decisions between risk and potential compensation. In addition, we propose a new analytical framework that integrates climate change, the irreplaceability of cultural heritage, and the risk management strategies of insurance companies, with a view to providing new ideas and practical suggestions in this area. Finally, we use a famous Japanese temple as a case study to practically analyze the level of protection and insurance measures for this structure.

2. Method

2.1. The method of CRITIC

Critic assignment method is calculated, r_{ij} is the degree of correlation between indicator i and indicator j. The specific algorithm is as follows:

$$r_{ij} = \frac{\sum(i-i)(j-j)}{\sqrt{\sum(i-i)^2 \sum(j-j)^2}} \tag{1}$$

Variability is considered to be the greater the difference between all the evaluation indexes of the same indicator, the greater the standard deviation, the greater the amount of information it contains, expressed as δ_i.

$$\delta_j = \sqrt{(x_i - \mu)^2} \tag{2}$$

Conflict is based on the correlation coefficient between the indicators, which is opposite to the correlation between the indicators, and the quantitative index of the conflict between the jth indicator and its indicators is as follows R_j.

$$R_j = \sum_{i=1}^{n}\left(1 - r_{ij}\right) \tag{3}$$

Where: n is the number of evaluations of the same indicator, and the objective weight of each indicator is measured by variability and conflict.

Set $C_j$to indicate the amount of information contained in the first evaluation indicator, then $C_j = \delta_j R_j$,for the formula factor. Let Y_j be the objective weight of the jth indicator.

$$Y_j = \frac{C_j}{\sum_j^m C_J} \tag{4}$$

An important step of the weight vector Y:$Y = \left[y_{1,} y_{2,} y_3 \ldots y_n\right]$

2.2. Classification of Extreme Weather Hazard

An affiliation matrix was constructed based on the combined weights to classify the extreme weather hazard. First, the number of deaths due to earthquakes from 1980 to 2020 is used to construct the indicator assessment set, V={v_1, v_2, v_3, v_4, v_5 }which corresponds to extremely high, high, medium, low, and low levels of danger. And build the original fuzzy evaluation matrix X' of the indicator data, the calculation formula is as follows.

$$X' = \begin{bmatrix} x'_{11} & \cdots & x'_{15} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{m5} \end{bmatrix} \tag{5}$$

Normalize the processing X' to obtain the fuzzy evaluation matrix X'calculation formula.

$$X = (x_{ik})_{m\times 5} \ \ (i = 1,2\cdots, m; k = 1,2,\cdots,5) \tag{6}$$

Synthesizing the fuzzy comprehensive evaluation matrix and synthesizing the weights yields the affiliation matrix P, which is calculated as follows:

$$P = Z \cdot X \tag{7}$$

Using the method of K-means clustering, each data in the matrix P is divided to obtain the division of the degree of extreme weather danger in five categories.

This determines the level of assessment of extreme weather risk, provides accurate warnings for different geographic areas, and realizes the assessment of extreme weather risk

2.3. Risk-return Modeling for Insurance Companies

This model mainly uses linear regression model and multiple regression model to measure the return of the insurance company when underwriting policies to help in extreme weather According to the model assumptions, the article approximate the insolvency of an insurance company as the insurance company's capital in a certain period of time is less than or equal to a given threshold Thr Based on the distribution of the number of policies under each risk to generate the random number $Z_\rho(k), \rho = 1,2,3\cdots, k = 1,2,3\cdots$, and then base on the probability of the occurrence of each risk, generate a series of multinomial distributed random numbers $O_\rho, \rho = 1,2,3\cdots$ where $O_\rho = (O_{1\rho}, O_{2\rho}, \cdots O_{k\rho})$. If $O_{ip} = 0$ then the risk will occur, otherwise B, the risk will not occur.

2.3.1 Establish the Risk-return Evaluation System of Insurance Companies

Based on the generated random numbers, the total income and total expenditure in year ρ are computed as Equations 1,2, respectively.

$$S_\rho = Z_{\rho(1)}W_{\rho(1)} + Z_{\rho(2)}W_{\rho(2)} + \cdots Z_{\rho(k)}W_{\rho k} \tag{8}$$

$$C_\rho = Y_{\rho(1)}W_{\rho(1)}O_{1\rho} + Y_{\rho(2)}W_{\rho(2)}O_{2\rho} + Y_{\rho(k)}W_{\rho(k)}O_{1k} \tag{9}$$

where K is the number of risk classes, p(k) denotes the probability of occurrence of each class of risk, Y(k) is the amount of money paid out by the insurance company under each class, and Z(k) the number of policies under each risk and the amount of money insured under each policy W(k).
The approximate probability is then$P_r\left(\sum_{\rho=1}^{L} S_\rho - \sum_{\rho=1}^{L} C_\rho > Thr\right) \ L = 1,2,3$

Repeat the above process N times to get the N*L matrix M. Each row of the M matrix represents a repetition, and each column represents the difference between income and expenditure in a year,$S_\rho - C_\rho$, then sum the profits to get the total profit in year ρ.

$$\sum_{L=1}^{L} S_{\rho(L)} - C_{\rho(L)} \tag{10}$$

Then the matrix M'=$\begin{pmatrix} S_{11} - C_{11} & \cdots & \sum_{i=1}^{i}(S_{1i} - C_{1i}) \\ \vdots & \ddots & \vdots \\ S_{N1} - C_{N1} & \cdots & \sum_{i=1}^{i}(S_{Ni} - C_{Ni}) \end{pmatrix}$

$$\equiv \begin{pmatrix} m_{11} & \cdots & m_{1N} \\ \vdots & \ddots & \vdots \\ m_{N1} & \cdots & m_{NN} \end{pmatrix}$$

Then the probability that the insurance company is not insolvent in L years is approximated as

$$P_L = \frac{1}{N}\sum_{i=1}^{N} I\left(m_{i\le j\le L} m_{ij} > Thr\right) \tag{11}$$

where the method approximation is sufficiently accurate when N is sufficiently large.

2.3.2 Model Optimization

(1) Consideration of increasing probability of disaster occurrence

The above model assumes that the probability of occurrence of each risk level remains constant, whereas in practice, the probability of occurrence of each risk has a tendency to constantly change.In order to consider this change, we establish a linear model of the probability of occurrence of risk versus time, where k is a constant.

$$P(k) = P_0(k) + \alpha_k \times t \tag{12}$$

The corresponding probability of insolvency can be obtained by simply correcting the above model.

(2) Considering various factors affecting the number of policies

In the above model, we assume that the number of policies comes from the same distribution, while in reality the number of policies may also change over time. The possible variables affecting the number of policies are the amount of premium, the amount of compensation and the probability of this level of disaster in the area. Therefore, we can develop a dynamic linear regression model for $Z_{\rho(k)}$.

$$Z_{\rho(k)} = \beta_{k1} Z_{\rho-1(k)} + W_{(k)} \times \beta_{k2} + Y_{(k)}\beta_{k3} + P_{\rho(k)} \times \beta_{k4} + \varepsilon_{\rho k} \quad \text{where A is white noise.} \tag{13}$$

Similar to the natural disaster risk assessment model, we can simulate the probability of an insurance company's insolvency in each year given the parameters.

3. Test results based on Sensoji Temple in Japan

3.1. Building Value Assessment Model

3.1.1 Indicator Selection

There are four areas of significance: cultural, historical, economic, and community. And within these four areas, there are many factors and indicators. In our model, we use McKinsey Logic Tree Analysis to select several important indicators to assess whether and to what extent a historic landmark should be protected in decision-making. The selected indicators are shown in Figure 1.

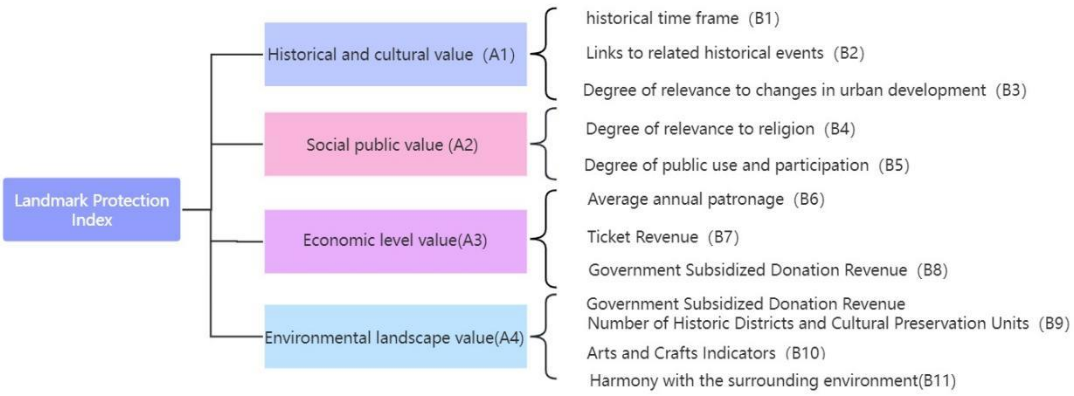

Figure 1 The Landmark Protection Index

3.1.2 Calculation of weights

We used hierarchical analysis to stratify the selected decision variables and then combined it with the CRITIC method to calculate the correlation between the indicators to determine the relative weight of each indicator.

3.2.1 Hierarchical analysis

(1) The importance of the main factors was compared by integrating the scores of nine experts on average from four fields. The results are:

History and Culture > Social Public > Economic Level > Environmental Landscape

(2) Calculation of Comparison Matrix

Through the relationship we discussed earlier, we get the comparison matrix (Cij) 4×4, as shown in Table 1.

Table1 Landmark Protection Index matrix

LPI	A1	A2	A3	A4
A1	1	2	3	5
A2	1/2	1	3	4
A3	1/3	1/5	1	3
A4	1/5	1/4	1/3	1

(3) Consistency test

We can calculate the eigenvalues and eigenvectors of the matrix before. Next, we need to perform the consistency test with the maximum eigenvalue max.

$$\mathrm{CI} = \frac{\lambda_{\max}}{n-1} \tag{14}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{15}$$

Based on the comparison matrix, CR were obtained and $\mathrm{CR} = 0.0403$ less than 0.1 , passed the consistency test.

(4) Calculate to get the weights

After ensuring the consistency of the decision matrix through the consistency test, we can find that, among the factors considered, the historical and cultural value is weighted at 0.463, the social and public value is weighted at 0.311, the value indicator of the economic level is weighted at 0.153, and the value indicator of the environmental landscape is weighted at 0.0718.

In order to ensure the robustness of the results, this paper adopts the method of arithmetic average, geometric average, and eigenvalue method, respectively, and calculates the average value after finding out the weights, and then calculates the scores of each program based on the obtained weight matrix. The conclusions drawn were more comprehensive and effective.

3.2.2 Combined weights with CRITIC

After calculating the variability, conflict, information and objective weight of each indicator according to equation, the subjective and objective weights are combined, and the results are shown in Table2. The combination of weights takes into account the advantages of subjective and objective weights, which makes the weight information obtained more scientific and precise.

Table 2 Combined Weights

	Hierarchical analysis weights	CRITIC Act weights	Combined weights
A1	0.463333333	0.13254	0.328928145
A2	0.3117	0.15058	0.251399621
A3	0.153133333	0.3305	0.271082651
A4	0.0718	0.38637	0.148589584

3.1.3 Landmark Protection Index

After obtaining the weights of the indicators, the landmark protection index for each country can be calculated by weighted summation. The top ten landmarks are Great Wall of China (L1), Colosseum, Italy (L2), Eiffel Tower, France (L3), Ancient City of Petra, Jordan (L4), Pyramids of Giza, Egypt (L5), Taj Mahal, India (L6), Old City of Jerusalem, Israel (L7), Sydney Opera House, Australia (L8), Statue of Liberty, USA (L9), Machu Picchu, Peru (L10). The specific indices are shown in Figure2.

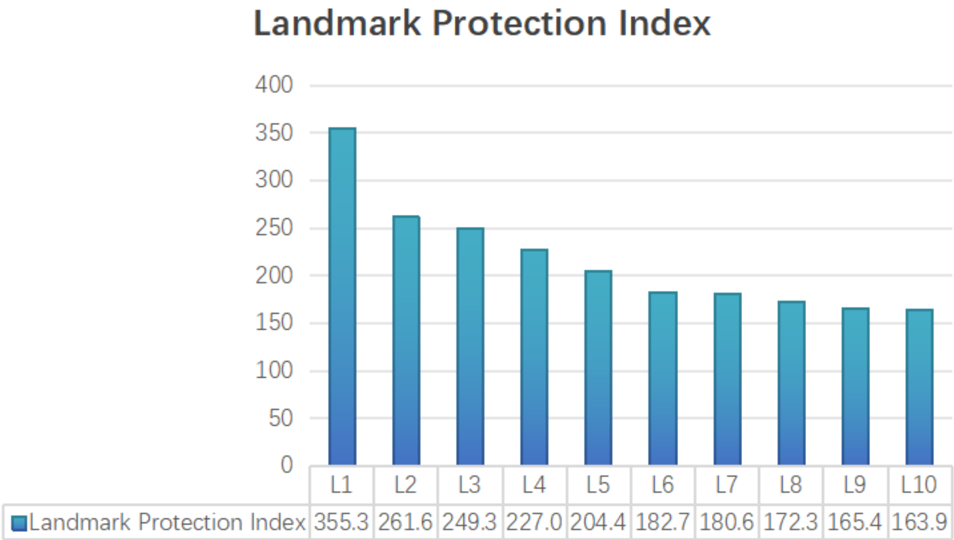

Figure 2 Landmark Protection Index of the Top 10 Landmarks

Therefore, we can conclude that when a building has a higher landmark protection index, it means that the building has a higher value in terms of history and culture, etc., and therefore more effort should be put into its preservation.

3.1.4 Empirical Analysis

In this paper, we chose Sensoji Temple, a historical temple in Japan, as a study case, and imported the collected data into the building conservation model we constructed for application, and finally calculated the conservation index of 229.6 within the Hokkaido Grotto Towers, which is second only to the index of the Eiffel Tower (ranked third) among the selected 30 buildings. This means that the building has a high conservation index and has high valuable historical and conservation value, and the government needs to take action to restore and protect these buildings.

3.2. Japan as an Example of a Natural Disaster, an Earthquake

In Asia, Japan serves as a prime example of high earthquake activity. According to the National Oceanic and Atmospheric Administration (NOAA), Japan has experienced 98 major earthquakes since 1990(Extreme weather data in Japan. Retrived from https://www.noaa.gov/.).

Given its geographical size, Japan has one of the highest earthquake frequencies globally. Therefore, this article selects data on Japan's earthquake experience from 1948 to 2023 as a natural disaster case study. Based on the entropy weighting method discussed above, weights are assigned to each indicator, with results as follows: number of deaths from earthquakes (N1, unit: persons): 21.008%; number of people injured by earthquakes (N2, unit: persons): 16.985%; number of people affected by earthquakes (N3, unit: persons): 21.124%; number of people left homeless by earthquakes (N4, unit: persons): 23.685%; insured damages from earthquakes (N5, unit: million USD): 6.441%; total economic damages from earthquakes (N6, unit: million USD): 10.757%.

The selection of these indicators is based on their relevance in capturing the multifaceted impacts of earthquakes. Each indicator provides insight into different aspects of damage, from human toll to economic consequences, thus offering a comprehensive basis for analysis.

By combining entropy weights and the hierarchical analysis method to determine the combined weight Z, and by using the calculation method in the above model, the risk level of the natural disaster of earthquakes as a natural disaster in Japan in the last 75 years was evaluated. The results are shown in Table3.

Table 3 Japan Earthquake Risk Classification

Hazard level	P-value	Implied meaning
I	P>0.0984	Very high risk
II	0.0141<P<0.1324	Hazardous high
III	-0.1155<P<0.0727	Medium risk
IV	-0.0149<P<-0.0157	Hazard low
V	P<-0.1311	Low risk

As a result, we apply the obtained data on the insurance company's revenue model. We chose the Monte Carlo simulation method to evaluate the risk of Japanese insurance companies under earthquake disaster. Based on these 123 years of earthquake data, we first calculated the frequency of occurrence of each class of earthquake as follows $8.94e^{-2}$, $7.32e^{-2}$, $1.63e^{-2}$, $7.32e^{-2}$, $1.63e^{-2}$. Next, we calculated the average loss and standard deviation for each risk level earthquake and fitted the loss for each risk level earthquake with a normal distribution. Based on the proportion of previous payouts to the overall loss, we used forty percent of the loss as the payout amount. We calculated the average number of people affected and the standard deviation for each risk class earthquake and fit the number of people affected with a normal distribution. For convenience, we assume that the number of insured people for each risk class is one million and assume that Thr is zero, i.e., an insurance company is declared insolvent when its cumulative profit is less than zero. Based on the ratio of the desired amount of payout for each risk class, we set the premiums for each class to w, 48.42w, 113.64w, 294.91w and 7731.82w, where w is the set premium amount. We get the probability of insolvency and cumulative profit under w=$2e^3$, $5e^3$, $1e^4$ as shown in Figure3. From the following figure, we can see that the smaller the premium amount, the higher the probability of bankruptcy in the first period and the lower the cumulative profit; the probability of insurance company's bankruptcy decreases with time, and the average cumulative profit increases with time, so the insurance company needs to have enough money to resist the risk in the first period.

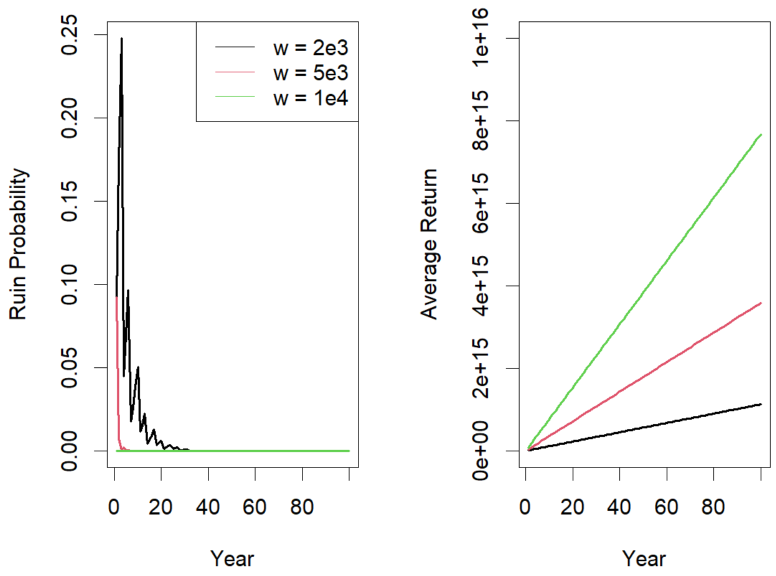

Figure 3 Ruin probability and average return in Japan

In the Figure4 we plot the probability of insolvency and the average profit for different numbers of insured for the premium amount w = 5000. From this figure we can see that the bankruptcy probability tends to become smaller over time and the cumulative profit tends to increase over time.

Moreover, the higher the number of insured, the lower the bankruptcy probability and the lower the cumulative profit.

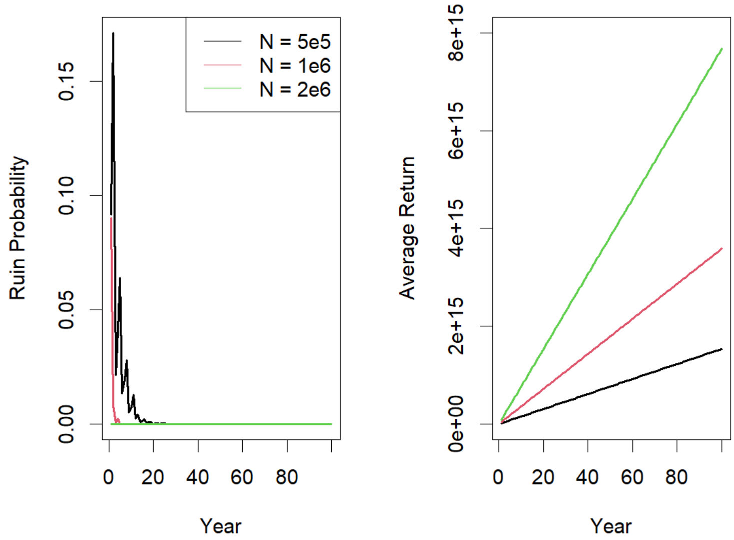

Figure 4 Ruin probability and average return in Japan

4. Conclusions

The article serves to provide a scientific and systematic assessment method for the protection of cultural heritage and the development of insurance measures, and verifies the feasibility and practicality of the model through a case study of Asakusa Temple in Japan. The article gives recommendations for insurance for the Asakusa Temple in Japan, i.e., in the face of increasingly frequent weather extremes, insurance companies should do sufficient market research to assess whether the number of insured people is large enough, whether the premium is acceptable, and whether there are sufficient funds to resist the risks that already exist, and to simulate the probability of the risks occurring according to the method proposed in this paper.

Although this paper provides a strong theoretical framework for cultural heritage insurance, there are some limitations. First, the weight assignment of the model relies on expert opinions and may be subjective; second, the K-means clustering method, although effective, may not be precise enough for categorization when facing more complex risk portfolios. In terms of future outlook, further introduction of more dynamic variables, such as climate change impacts and long-term economic benefit assessment, will help to further improve the model. Meanwhile, by introducing smarter risk prediction tools, such as machine learning, insurers will be able to more accurately assess risks and adjust underwriting programs.

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