

A Study on Insuring Climate Risks of Historical and Cultural Heritage Based on Comprehensive Weighted Risk-Benefit Models and Cultural Value Assessment Models

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Abstract. In the context of global climate change, the frequency of extreme weather events poses a serious threat to historically rich buildings around the world, and there is an urgent need to insure cultural heritage against climate risk in order to cope with potential catastrophes. The core challenge is how to accurately measure the level of extreme weather risk in different regions and quantitatively assess the unique historical and cultural values of buildings. This paper have constructed a comprehensive weighting model, an Underwriting Risk-Benefit Model (URBM), and a cultural value assessment model, which are scientifically and rigorously used to quantify the potential damage to cultural heritage caused by extreme weather and the intrinsic cultural value of the buildings, respectively. Using this combination of models, this article aim to help insurance companies to design accurate insurance strategies, and at the same time provide targeted and practical risk prevention, control and protection solutions for cultural heritage holders to ensure that valuable cultural heritage can be properly preserved and inherited in the future climate challenges, and inject new scientific power and decision-making tools into the global cultural heritage risk management practice.

Keywords: Insuring Climate Risk, Historical and Cultural Heritage, Integrated Weighting Models, Underwriting Risk-Benefit Models, Cultural Value Assessment Models.

1. Introduction

Against the backdrop of frequent extreme weather events and increasing disaster losses around the world, the insurance industry is under unprecedented pressure, and built heritage, which is rich in deep historical and cultural values, is facing unprecedented threats [1]. The existing insurance system is often inadequate in dealing with such complex risks due to limited assessment tools and difficulties in quantifying values, making it difficult to provide adequate and effective protection. Therefore, how to accurately assess the potential damage of extreme weather on historical and cultural heritage and scientifically quantify its multiple values have become the key to formulate an insurance strategy that takes into account both risks and benefits, and to provide heritage owners with practical risk management solutions.

To address this issue, scholars at home and abroad have conducted extensive research on climate risk and its coping strategies, providing theoretical background and practical references for the prevention and control of climate risk insurance for historical and cultural heritage. Among them, the DICE model and its generalized lognormal distribution function constructed by Liang Rong and Chen Bingzheng quantify the potential loss of global GDP due to extreme weather [2], which provides a quantitative framework for understanding climate risk at the macroeconomic level, but its focus is mainly on the economic system at the global scale, and its relevance to specific regions, especially historical and cultural heritages, is limited. Taking rice in Jiamusi City as an example, Yang used rainfall as the optimal weather index and enhanced the robustness of the yield-weather index relationship model through a two-dimensional Copula function [3], which provides an example for modelling the relationship between specific climate factors and agricultural output [4]. However, for non-agricultural production objects such as historical and cultural heritage, there are significant differences in climate risk characteristics, impact mechanisms and corresponding insurance product

designs, and direct application of such models may not be applicable. Zeng Xiaoyan developed a weather index insurance product adapted to China's national conditions by using a panel data model and an ARIMA time series model, which is a valuable guide for the localisation of climate insurance in China. However, due to the characteristics of historical and cultural heritage, such as non-renewable, diversified cultural values, and high protection costs, it is difficult to accurately capture the unique risk characteristics and loss estimation needs of the conventional weather index insurance framework.

Overseas Lucas et al. explored the opportunities and challenges of emerging insurance models among low-income households during extreme weather [5], revealing that insurance demand is affected by informal networks, misperceptions, and lack of trust [6]. Although this study deepens the understanding of the role of the insurance market in responding to extreme weather, historical and cultural heritage, as an insured subject with public attributes, high cultural value and international attention, has its own specificities in terms of risk perceptions, insurance needs and market mechanisms, which need to be treated differently. Other studies, such as Abbas et al.'s analysis of willingness to pay for non-structural flood risk mitigation and Adger and O'Brien's focus on social contract change and resilience building in climate change adaptation, have provided a macro perspective on climate risk management, but specific to the prevention and control of climate risk insurance of historical and cultural heritage, it is necessary to take into account its unique cultural value, preservation needs, and resource allocation characteristics [7]. However, when it comes to the prevention and control of climate risk insurance for historical cultural heritage, it is still necessary to combine its unique cultural value, protection needs and resource allocation characteristics.

In summary, previous studies have made important progress in climate risk assessment, weather index insurance design, claim model construction, etc. However, for historical and cultural heritage, which is a special insured subject, the existing studies have deficiencies in the precision of risk identification [8-9], customisation of insurance products, and the consideration of cultural value, etc. Hence, this study adopts a comprehensive weighting approach [10]. Therefore, this study adopts a comprehensive weighted risk-benefit model and a cultural value assessment model, aiming at overcoming the above limitations, accurately portraying the climate risk characteristics of historical cultural heritage, taking into account the economic benefits and the protection of cultural value, and providing strong support for the development of a scientific and comprehensive prevention and control strategy of climate risk insurance for historical cultural heritage.

2. Composite Weighting Model

This chapter evaluates the insurance risks of insurance companies in a certain area from two aspects: natural disasters and socio-economic conditions. On the basis of extensive data collection, an AE-Evaluation risk-adjusted insurance benefit evaluation model is established to calculate the weight of each index, so as to achieve a comprehensive assessment of the insurance risk of a certain area in the context of the increase in the number of extreme weather events.

2.1. The derivation process of Composite Weighting Model

The analytic hierarchy process (AHP) is used to decompose the problem into different components, and these factors are aggregated at different levels to form a multi-level analysis structure and determine the weight of each factor. The method includes the following steps:

Step 1: Establish a hierarchical structure model.

According to their interrelationships, they are divided into the highest layer, the middle layer and the lowest layer, and a hierarchical structure diagram is drawn.

Step 2: Fill in the judgment matrix and construct the subjective evaluation matrix.

In the hierarchical structure model from the second layer, in order to construct the judgment matrix for the same layer of each factor in the previous layer, until the bottom layer, the corresponding nine-level scale is used for pairwise comparison, and the judgment matrix is generated.

The elements a_{ij} of the judgment matrix represent the comparison result between the i th factor and the j th factor. $a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}}$: $A = (a_{ij})_{n \times n}$.

Step 3: Use the square root method to calculate the relative weight of the standard.

Step 4: Consistency test judgment.

Define consistency metrics: $CI = \frac{\lambda - n}{n - 1}$ Among them λ : the maximum characteristic root unique non-zero eigenvalues. $CI=0$, there is complete consistency CI is close to 0, with satisfactory consistency; the larger the CI , the more serious the inconsistency.

In order to measure the size of CI , the random consistency index RI is introduced. Define the consistency ratio $CR = \frac{CI}{RI}$. In general, when the consistency ratio $CR < 0.10$, it is considered that the degree of inconsistency of A is within the allowable range, and there is satisfactory consistency, which passes the consistency test. At this time, its normalized feature vector is used as the weight vector.

Through the above steps, we get the target weight vector $h_i (i = 1, 2, \dots, m)$.

Secondly, the entropy method (EWM) is used to calculate the objective weight (importance) of each variable according to the size of the index variability. The method includes the following steps:

Step 1: Data standardization.

Each index is dedimensionalized. Suppose form indicators: where. Suppose that the standardized value of each indicator data is $\{Y_1, Y_2, \dots, Y_n\}$, then

$$Y_{ij} = \frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)} \text{ (When positive indicators)} \quad (1)$$

$$Y_{ij} = \frac{\max(X_i) - X_{ij}}{\max(X_i) - \min(X_i)} \text{ (When negative indicators)} \quad (2)$$

Step 2: Find the ratio of each index under each scheme.

$$p_{ij} = \frac{Y_{ij}}{\sum Y_{ij}}, i = 1, \dots, n, j = 1, \dots, m \quad (3)$$

Step 3: Find the information entropy of each index.

$$E_j = -\ln(n)^{-1} \sum p_{ij} \ln p_{ij} \quad (4)$$

Where $E_j \geq 0$. If $p_{ij} = 0$, define $E_j = 0$.

Step 4: Determine the weight of each index.

According to the calculation formula of information entropy, the information entropy of each index is calculated as E_1, E_2, \dots, E_j

The weight of each index is calculated by information entropy:

$$w_i = \frac{1 - E_j}{k - \sum E_j} (i = 1, 2, \dots, m) \quad (5)$$

Here refers to the number of indicators, $k = m$.

Next, the following formula is used to combine the entropy weight method with the weight calculated by AHP.

$$S_i = \frac{w_i \cdot h_i}{\sum (w_i \cdot h_i)} \quad (6)$$

Where S_i is the comprehensive weight of each index, h_i is the weight calculated by AHP method, and w_i is the weight calculated by EWM method.

2.2. Underwriting Risk-benefit Model (URBM)

Firstly, the comprehensive evaluation function of risk is introduced:

$$RISK = \sum S_i \cdot Risk_i \quad (7)$$

Among them, RISK represents the comprehensive risk coefficient affected by extreme weather, Si is the comprehensive index weight of each index obtained in the previous section, and Risk_i is the risk coefficient of each index itself.

Without considering individual factors, we can approximately assume that the Claims Rate (RC) is equal to the risk coefficient we obtained. We can establish the following equations.

$$C_c = RC * NI * CA * \frac{1}{(1+i)^t} \tag{8}$$

NI represents the number of policies, CA represents the average amount of a single claim, t represents the time, i represents the time value discount rate of the funds, and C_c represents the total amount of the claim.

The total amount of the claim is approximately equal to the estimated loss (E) without considering the noise of operating costs, default losses, etc.

Here we introduce the underwriting risk factor Q, which is calculated as follows:

$$Q = \frac{C \cdot P - E(L)}{P} \tag{9}$$

Among them, C represents the insurance company’s own underwriting capacity parameters. Here we set its range to 0-1 and also use randomly generated simulation parameters. P represents the premium, and E (L) represents the estimated loss of the region in the current year. Economic capital =C · P.

$$C = C_f + C_v * Q \tag{10}$$

Total production cost = fixed cost + variable cost = fixed cost + unit variable cost * production and sales volume (number of insurance sales / number of insurance policies)

$$B = P * Q \tag{11}$$

Sales revenue = average sales unit price * number of policies (excluding tax)

Risk-adjusted return on capital (RAROC) takes into account risk factors. The formula is:

$$RAROC = \frac{I - C - E}{C \cdot P} \tag{12}$$

Income (I) refers to the total income of the insurance company, including premium income and other operating income; the expected loss (E) refers to the sum of the expected losses of different risks calculated by the insurance company; cost (C) refers to the various costs in the daily operation of insurance companies.

2.3. Cultural Value Assessment Model

(1) Architectural culture building rating system

Saudi Arabia heritage classification and selection criteria reference evaluation: case study of Balzan heritage area in Haier City. The cultural heritage evaluation system includes six key main evaluation indicators. Specific indicators are shown in Table 1.

Table 1. Six parameter indicators.

Age and historical value (A)	Taking into account the age of the building and the depth of the historical information it carries.
Historical Importance (H)	Assesses the role and event relevance of architecture in the history of the country and the region.
The scarcity feature (J)	Analyzes the uniqueness and scarcity of such buildings on a global scale.
Integrity (M)	Measures the integrity of the original state of the building and the extent of the current damage.
Architectural aesthetic value (N)	Evaluates the artistic style, structural details and visual effects of architecture according to the aesthetic principles of architectural design.
Future economic space (K)	Predicts the potential economic benefits and development prospects of tourism resources and commercial investment development.

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(2) Weight Calculation System

(a) Establish a hierarchical structure model;

The highest level (target layer): a scientific and detailed quantitative evaluation of the historical and cultural value of the building itself.

Middle layer (criterion layer or index layer): age and historical value (A), historical importance (H), scarcity characteristics (J), integrity (M), architectural aesthetic value (N), future economic space (K)

(b) Construct judgment (pairwise comparison) matrix;

A pairwise comparison matrix is a comparison of the relative importance of all factors at this level against a certain * factor (quasi-side or target) * at the previous level. The element a_{ij} of the pairwise comparison matrix represents the comparison result of the i -th factor relative to the j -th factor, which is given by Santy's 1-9 scale method. Specific indicators are shown in Table 2.

Table 2. 1-9 scale method.

Relative importance	Definition
1	Equally important
3	Slightly important
5	Quite important
7	Obviously important
9	Absolutely important
2, 4, 6, 8	The intermediate value of two adjacent judgments
1/3	Slightly unimportant
1/5	Quite unimportant
1/7	Obviously not important
1/9	Absolutely not important
1/2, 1/4, 1/6, 1/8	The intermediate value of two adjacent judgments

(c) Solving the eigenvector of the judgment matrix. The approximate value of the matrix eigenvector is calculated by the square root method.

The first step is to calculate the n -th root of the product of each row element of the judgment matrix A , and the formula is as follows:

$$M_i = \sqrt[n]{\prod_{j=1}^n a_{ij}} \tag{13}$$

The second step is to normalize M_i , and the formula is as follows:

$$W_i = \frac{M_i}{\sum_{i=1}^n M_i} \tag{14}$$

The third step is to calculate the maximum eigenvalue of the judgment matrix:

$$\lambda = \sum_{i=1}^n \frac{(Aw)_i}{mw_i} \tag{15}$$

(4) Test the consistency of judgment matrix.

CI is the deviation consistency index of the measurement judgment matrix, $CI = (\lambda - n) / (n - 1)$. The larger the CI, the worse the consistency of the judgment matrix. When CI is 0, the judgment matrix has complete consistency.

CR is the consistency ratio, and the formula is: $CR = CI / RI$, where RI is the average random consistency index. When $CR < 0.1$, the consistency of the judgment matrix can be considered acceptable.

(5) Synthetical Evaluation System

$$F_i = W_A * A + W_H * H + W_J * J + W_M * M + W_N * N + W_K * K \tag{16}$$

F_i indicates the comprehensive importance score of building i .

3. Results

3.1. Comprehensive Weight Model Results

In order to establish the most suitable evaluation system to specifically assess the risk of insurance, we identified indicators from both natural disasters and socio-economic conditions. Specific indicators are shown in Table 3.

Table 3. Indicator framework table.

Level I	Level II	Explain	Unit
Nature	Wildfire	Uncontrolled vegetation fires spreading quickly.	time
	Flood	Overflow of water onto normally dry land.	time
	Hurricane	Severe tropical cyclone with strong winds and heavy rain.	time
	Drought	Prolonged period of abnormally low precipitation.	time
	Earthquake	Sudden ground shaking caused by tectonic movements.	time
Society and Economy	Population density	Number of people per unit area.	Person/ hectare
	Human made disasters	Catastrophes resulting from human actions or negligence.	Time
	GDP	Total value of goods and services produced in a country.	Dollar

After the calculation of the comprehensive weight model, the final weight of each index is shown in Figure 1.



Figure 1. AHP-EWM composite index weight.

It can be seen from Figure 1 that natural disaster factors have a greater impact on insurance risks than socio-economic conditions. This result has a strong correlation with the main research background of this paper, ' increased extreme weather '. The order of influence of natural factors is different from the order of damage caused by traditional natural disasters. Among them, hurricanes

have the greatest impact, which is due to the fact that the frequent occurrence of hurricanes in recent years is an important manifestation of the increase of extreme weather. The earthquake is second, because the earthquake itself has a large range of influence and great destructive power. Mountain fires are at the bottom, because mountain fires are mainly caused by the great destruction of natural resources such as forests, and the destruction of residents ' property is relatively small. It can be seen that the weight result has strong rationality.

3.2. Underwriting Risk-Return Model (URBM) Results

In order to verify the accuracy of the URBM model, we selected British Columbi in western Canada for calculation and analysis. According to the URBM model, the underwriting risk factor Q in this region is 20.87%, and the return on capital RAROC is 24.32%.

Western Canada has high summer temperatures, low precipitation, high winds, and susceptibility to mountain fires. Therefore, we chose British Columbia, Canada, as our case analysis in North America. As a country in North America, although the return on capital is not very high, the wind underwriting risk factor in this region is small, so it is suggested that insurance companies undertake to write insurance in this area.

There are many wildfires in western Canada, but due to the sparsely populated Canada, a wildfire is not particularly large for residents ' housing losses, and residents ' willingness to insure real estate insurance is at a medium level. However, this also reduces the compensation rate and the risk of compensation is relatively small. By comparing the model results with the actual situation, it can be found that the two are basically the same, so the above model has strong practical significance.

3.3. The Results of Cultural Value Evaluation Model

After in-depth analysis of the chromatographic analysis method, we obtained the following optimized results based on the criticality of the six indicators. Specific indicators are shown in Table 4 and Table 5.

Table 4. Proportion of Six Major Indicators.

The results of AHP hierarchical structure analysis				
Project	Eigenvector	Weighted value	Maximal characteristic root	CI Price
Age / historical value	0.628	10.469		
Historical importance	0.755	12.584		
Characteristics of scarcity	0.938	15.639	6.095	0.019
Integrity	0.838	13.973		
Architectural aesthetic value	1.603	17.723		
Future economic space	1.777	29.612		

Table 5. Stanley Park totem pole economic and cultural value analysis.

Stanley Park totem pole economic and cultural value analysis table							
	Age / historical value	Historical importance	Characteristics of integr scarcity	ity	architectural aesthetics value	Future economic space	total score
Weighted value	10.469	12.584	15.639	13.973	17.723	29.612	100
Score	30	15	20	35	30	50	180
Weight Score	3.1407	3.7752	4.6917	4.1919	5.3169	8.8836	30

According to the results, the comprehensive importance score of the totem pole in Stanley Park is 30 points, which shows that as a text and a practical situation, the totem pole is a treasure of the aboriginal culture of the northwest coast, carrying a profound cultural connotation, which is of great significance for the study of aboriginal culture, history and social structure. At the same time, as a

cultural symbol, totem pole also promotes the communication and understanding between different cultures and enhances cultural diversity and inclusiveness. In addition, as a unique tourism resource,

Totem pole has attracted a large number of tourists to watch and experience. Their existence not only enhances the popularity and attractiveness of Stanley Park, but also injects a strong impetus into the development of local tourism.

In summary, from the comparison between the predicted results and the actual situation, the cultural value evaluation model has better evaluation performance, relatively small error, fast prediction speed and convenient operation.

4. Conclusions

This study addresses the threats of extreme weather to cultural heritage by developing three models. The Comprehensive Weight Model assesses risks considering natural disasters and socio-economic factors. The Underwriting Risk-Benefit Model (URBM) evaluates insurance schemes' viability by factoring in extreme weather probabilities and potential losses. The Cultural Value Assessment Model quantifies the unique value of cultural heritage across cultural, historical, economic, and community dimensions. These models aid in creating tailored insurance products and managing risks for cultural heritage, ensuring their preservation amidst environmental challenges.

While the models show promise, there is room for improvement, particularly in enhancing predictive capabilities with tools like deep learning. There is a need for stronger interdisciplinary approaches to understand climate impacts on cultural heritage comprehensively. The models should also integrate real-time monitoring and disaster recovery mechanisms. Lastly, the models must be flexible to accommodate the specific conditions of different regions, reflecting local characteristics in protection strategies.

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