A Study on Maximizing Insurance Company Profits under Extreme Weather Events Based on an Optimization Model

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Abstract. This study investigates the ramifications of extreme weather events on property damage and the consequential claims pressure experienced by insurance companies. An optimization model is proposed to maximize insurance profits by balancing risk factors. Through this model, optimal insurance amounts are determined for two regions: Kentucky, USA, and Taiwan, China. In Kentucky, the predicted optimal insurance amount is $51,040.33, with insurers willing to bear maximum losses of $5,436.27. In Taiwan, the optimal insurance amount is $27,210.1, with maximum acceptable losses of $2,600.43. Furthermore, the study forecasts a decline in insurance amounts over time in Kentucky, attributed to factors such as population growth and real estate development. Additionally, a building conservation index model is introduced to aid in assessing and preserving valuable structures in regions unsuitable for insurance. This model offers a comprehensive approach to building preservation, incorporating cultural, historical, economic, social, and scientific values.

Keywords: Extreme weather events, Insurance companies, Building preservation, Optimization model.

1. Introduction

The sustainability of property insurance is increasingly scrutinized worldwide, with its core purpose being to mitigate risk through manageable premiums, as articulated by economist Milton Friedman. However, escalating global warming-induced extreme events, like floods and wildfires, pose a significant threat to insurers and policyholders alike. This necessitates a delicate balance between insurer profitability and policyholder affordability. In this study, we aim to address this challenge by examining ways to adapt insurance models to evolving risk landscapes, protect structurally significant buildings, and evaluate the value of historical landmarks. By doing so, we contribute to the discourse on sustainable property insurance, offering pragmatic solutions for stakeholders [1].

2. Property insurance sustainability modeling under climate change

2.1. Profit optimization model for insurance companies.

In this section, we consider the profit maximization of the insurance company. Therefore, we use the difference between the cost of insurance and the amount of compensation to construct an objective function for maximizing the insurer's profits. The function expression is as follows:

$$W = \max\left[n \cdot x - n \cdot P(N.\varepsilon) \cdot y\right] \tag{1}$$

Where W represents the profit, n represents the number of participants, x represents the premium, P represents the extent of building damage in extreme weather, y represents the actual

amount of money paid out by the insurance company, N represents the number of times in a year that an extreme weather event occurs, and ε represents the probability of building damage in the event of extreme weather [2].

From the analysis of the above objective function, we first determine the $P(N,\varepsilon)$ calculation method:

$$P(N,\varepsilon) = f(N) \cdot \varepsilon \tag{2}$$

Where $f(N)$ represents the probability of an extreme weather event occurring in a year and ε represents the probability of building damage when extreme weather occurs. Where the value of ε is smaller when the quality of the building is better.

Next, we calculate the probability of extreme weather occurrence and the amount of loss, and we use the expectation and variance in statistical analysis to calculate the frequency of extreme weather.

$$\begin{cases} E(N) = \sum N_i f(N) \\ Var(N) = E[N^2] - E(N)^2 \end{cases} \tag{3}$$

Where $E(N)$ is the expectation of the frequency of extreme weather events in a year, and the variance of the $E(N)$ frequency of extreme weather events $Var(N)$ in a year. According to Shaw's findings, we use Monte Carlo simulations to obtain the probability of the frequency of extreme weather events in a year by subordinating N to the Poisson distribution $f(N)$ [3].

We use the Weibull distribution to describe the losses caused by the occurrence of extreme events in a year and the formula is as follows:

$$\begin{cases} E(X) = \lambda \cdot \tau \cdot (1 + \frac{1}{k}) \\ Var(X) = \lambda^2[\tau\left(1 + \frac{2}{k}\right) - r^2\left(1 + \frac{1}{k}\right)] \end{cases} \tag{4}$$

Where is the X amount of damage from extreme weather events in a year, the expectation of the amount of damage from extreme weather events in a year, and the variance of damage from extreme $E(X)$ weather events in a year $Var(X)$. At that time, extreme weather events $k > 1$showed an "increased failure rate", which means that the probability of extreme weather events occurring is on the rise over time.

We then calculate the cost of insurance, which is related to the expectation of extreme weather in the area, which is calculated as follows:

$$H = \begin{cases} H_L = \pi_L E(x), \pi_L = 0.4, while\ 0 \le \pi \le 0.4 \\ H_H = \pi_H E(x), \pi_H = 0.6, while\ 0.4 < \pi \le 1 \end{cases} \tag{5}$$

Where H represents the total insurance cost to be paid in the region H_L, represents the H_H premium that needs to be paid when the risk of extreme weather in the region is low, and is the severity of the extreme weather in the region.

Based on the above formula, we can get the premium that the insured individual should pay as follows:

$$x = \frac{H}{N} \tag{6}$$

In this formula x, the premiums payable by insured individuals N are all individuals injured in disasters in the area, including insured and uninsured.

The amount of insurance (i.e., the maximum amount of compensation paid by the insurance company) can be obtained from the insurance cost as follows:

$$M = \frac{x}{\epsilon} \cdot \beta \tag{7}$$

Where is the M insured amount and the β adjustment factor.

Among them, the selection method of the insured amount (M) and the insurance compensation amounty is as follows:

$$\begin{cases} y = \frac{E(x)}{N}, while \frac{E(x)}{N} \leq M \\ y = M, while \frac{E(x)}{N} > M \end{cases} \tag{8}$$

That is, when the amount of loss is less than the insured amount, the insurance company will compensate according to the actual loss. When the amount of loss is greater than the insured amount, the insurance company pays the insured amount, that is, the compensation amount is equal to the insured amount.

Maximizing revenue is a key goal for insurance companies. The amount of income is related to the number of insured peoplen. As the number of insured people increases, insurance companies can better diversify risks and reduce the fiscal crisis of insurance companies. The number of insured people is related to the rate of insurance products, the credibility of the company, and the risk awareness of citizens.

Rate: Refers to the ratio of the insured person's premium to the insured amount. The lower the rate, the more customers can be attracted to buy insurance, which is conducive to the increase in the number of insured people [4].

$$F = \frac{x}{M} = \frac{x}{\frac{x}{\epsilon} \cdot \beta} = \frac{\varepsilon}{\beta} \tag{9}$$

Where F, represents the rate, and it can be seen from the derivation process of the equation that the better the quality of the building, the lower the rate, and the lower the willingness to buy insurance, which is consistent with reality.

Credibility: Insurance companies with high credibility will have more customers to choose. Here, we choose to measure the number of repeat purchasers against the total number of insured people.

$$\eta = \frac{n_{\propto}}{n} \tag{10}$$

Where η is the credibility and $n_{\propto}$ is the number of repeat purchasers.

Citizens' risk awareness: In disaster-prone areas, citizens' risk awareness levels are high, and the number of people willing to buy insurance is also higher.

$$A = \alpha \cdot n \cdot E(N) \tag{11}$$

Where, A is the greater the level of risk awareness for citizens, α the greater the number of people who buy insurance.

In summary, to measure the relationship between the number of insured population and these three influencing factors, we established a regression model based on historical data from previous years.

$$n = a + b_1 x_1 + b_2 x_2 + b_3 x_3 \tag{12}$$

Where a represents a constant term, x_1 represents the rate, x_2 represents the credibility, and x_3 represents the citizen's risk awareness. The b_1, b_2, b_3 are the correlation coefficients of rate, credibility, and citizen risk awareness.

In summary, we get the decision model of profit optimization of insurance companies as follows:

$$\mathrm{W} = \max\left[n \cdot x - n \cdot P(N, \varepsilon) \cdot y\right] \tag{13}$$

$$\text{s.t.}\begin{cases}\begin{cases} E(N) = \sum N_i f(N) \\ Var(N) = E[N^2] - E(N)^2 \end{cases} \\ \begin{cases} E(X) = \lambda \cdot \tau \cdot \left(1 + \frac{1}{k}\right) \\ Var(X) = \lambda^2 \left[\tau\left(1 + \frac{2}{k}\right) - r^2\left(1 + \frac{1}{k}\right)\right] \end{cases} \\ H = \begin{cases} H_L = \pi_L E(x), \pi_L = 0.4, while\ 0 \le \pi_L \le 0.4 \\ H_H = \pi_H E(x), \pi_H = 0.6, while\ 0.4 < \pi_H \le 1 \end{cases} \\ M = \mathrm{x} \cdot F \\ \begin{cases} y = E(x), while\ E(x) \ge M \\ y = M, while\ E(x) \le M \end{cases} \\ \eta = n_{\propto}/\mathrm{n} \\ A = \alpha \cdot n \cdot E(N) \end{cases} \tag{14}$$

Here, we introduce the concept of a claim cap to illustrate. That is, when the insurance company's claim amount exceeds the profit amount, we believe that the insurance company will not pay, and the critical conditions are:

$$W = [n \cdot x - n \cdot P(N, \varepsilon) \cdot y] = 0 \tag{15}$$

In this formula $W = 0$, the insurance company does not cover the policy, and the amount that the insurance company can compensate for the loss of personal assets is. Because in this case, the insurance company is in a state of unprofitability, which is not conducive to the operation of the insurance company. y is the insurance company does not pay out.

From the above constraints, when the insurance company does not pay, the creditworthiness will decrease, which will lead to a decrease in the number of insured people.

2.2. Apply the model to two places where extreme weather occurs.

To select two locations around the world that meet our requirements, we first mapped out the occurrence of extreme weather events around the world, as shown in the Fig. 1 below.

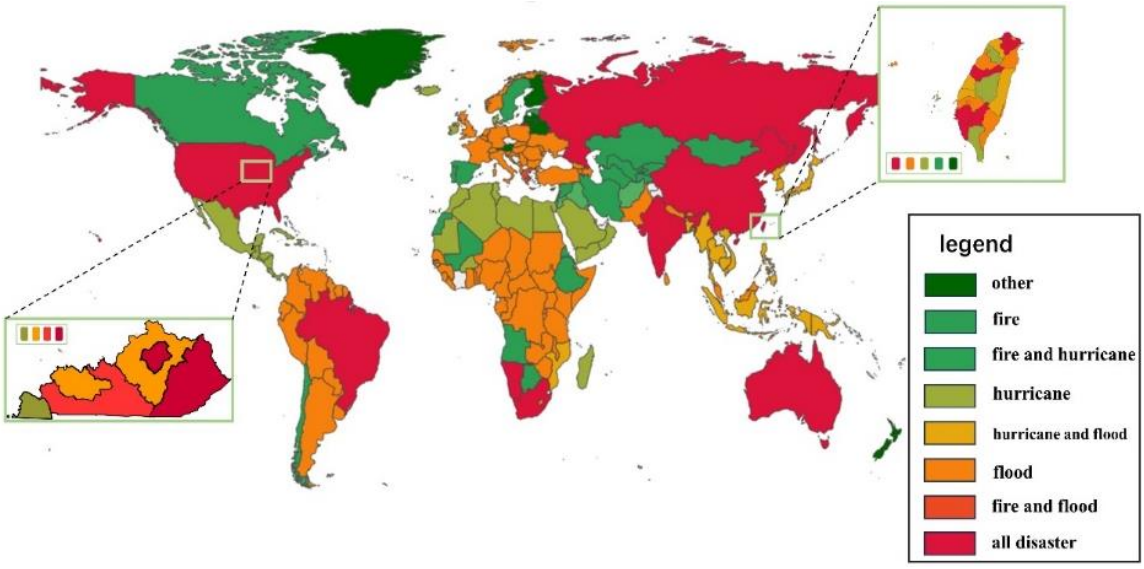


Figure 1. Major meteorological disasters in various countries and regions around the world

In addition to incorporating the frequency of extreme weather events, our analysis also integrates demographic factors, insurance industry operations, local insurance demand, and building resilience [5]. Consequently, our focus is directed towards regions meeting these criteria. Kentucky in North America and Taiwan in Asia were selected as the validation regions due to their alignment with these considerations. Kentucky has a history of enduring various extreme weather phenomena, including severe sandstorms, torrential floods, intense heatwaves, and wildfires, exerting profound impacts on

resident livelihoods. Moreover, Kentucky boasts a substantial permanent population and robust infrastructure, thereby amplifying the necessity for insurance coverage among its residents. Similarly, Taiwan Province, with an estimated resident population of 23.83 million in 2022, features comprehensive facilities and a plethora of insurance providers. Given the prevalent risk of extreme weather events in both regions, we set the severity parameter for such events at π 0.6. This strategic selection enables a robust validation of our model against real-world scenarios, encompassing diverse geographical and socio-economic contexts.

Applying the above model to the U.S. state of Kentucky, we get that the cost of insurance should be $306.238, the insured amount is $51,040.33, which is equal to the price of local real estate.

- Discussion of the company's underwriting policies

We calculated that the critical condition for the company's profit to be zero is that the risk of asset loss due to extreme weather in the area is 0.012, and the amount of personal loss is $5436.27.

- The results of the return process regarding the number of insured persons are determined.

$$n = 1.662 - 0.0028x_1 + 0.035x_2 + 0.234x_3 \tag{16}$$

Where the regression coefficient of the rate is negative, meaning that the rate is negatively correlated with the number of people who buy insurance. This means that the lower the upper limit of the sum insured, the fewer people will buy insurance. The regression coefficient of credibility and citizen risk awareness is positive, indicating that the number of npeople is positively correlated with both, that is, the higher the level of citizens' risk awareness and the credibility of the company, the more people buy insurance. Among them, the credibility of the company has a greater impact on the number of insured people.

We adjust the rates, the credibility of the company, and the risk awareness level of citizens, and the results are shown in Figs. 2 (a) and (b), respectively.

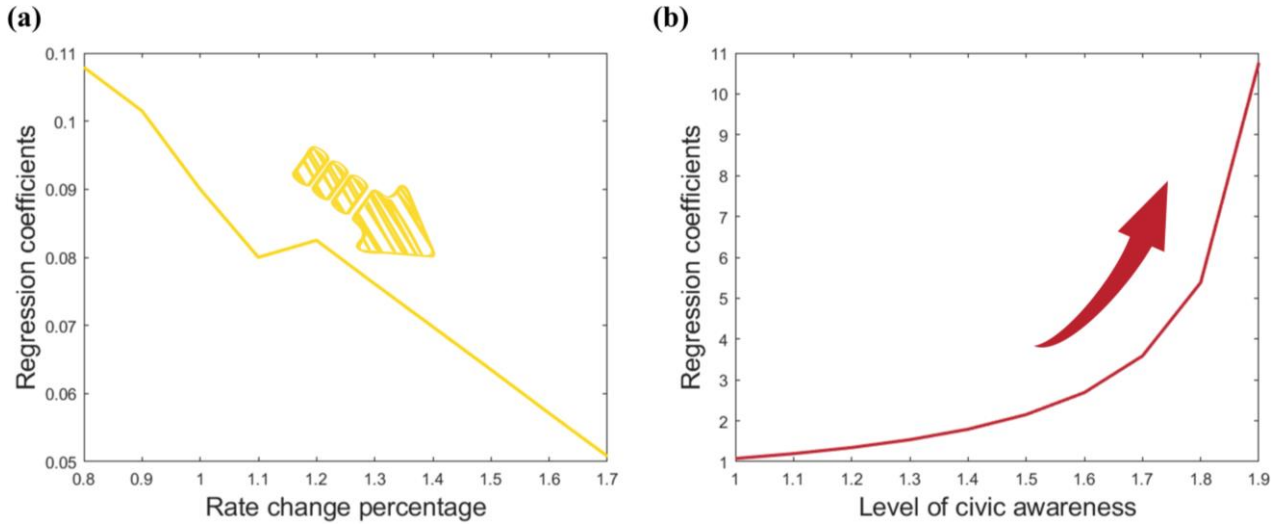


Figure 2. Impact of rates (a), citizens' level of risk awareness (b) on the number of insured people

As shown in the Fig., an increase in rates will lead to a decrease in the number of insured people, and an increase in the level of risk awareness of citizens will lead to an increase in the number of insured people. This is the same result we expected.

After applying the above model to Taiwan, we get that the insurance cost should be $170.069 and the insurance amount should be $27,210.1.

- Discussion of the company's underwriting policies

We calculated that the critical condition for the company's profit to be zero is that the risk of asset loss due to extreme weather in the area is 0.015 and the amount of personal loss is 2600.43 US dollars.

- The results of the regression equation regarding the number of people who have purchased insurance are determined.

$$n = 2.662 - 0.0639x_1 + 0.0159x_2 + 0.960x_3 \quad (17)$$

In the formula, the regression coefficient of the rate is negative, and the regression coefficient of creditworthiness and citizen risk awareness is positive, and the results obtained are like those in Kentucky, which will not be discussed here.

3. Adapting to demographic and building quality changes: Insurance strategies in future neighborhood development

3.1. Optimization of the objective function

In this section, we consider time to more than the objective function in Section 4 to discuss how the change in the frequency of extreme weather in a year and the probability of building loss in the event of extreme weather affect the change of insurance model as time t increases. The optimized objective function is as follows:

$$W = \max [n \cdot x - n \cdot P(N.\varepsilon, t) \cdot y] \quad (18)$$

Where represents the change in the degree of damage caused by extreme weather over time, and the meaning of the remaining parameters remains the same. where, the expression is as follows:$P(N.\varepsilon, t)tP(N.\varepsilon, t)$

$$P(N.\varepsilon, t) = f(N, t) \cdot \varepsilon(t) \quad (19)$$

Where $f(N, t)$ denotes the frequency of extreme weather events over time in a year, $t\varepsilon(t)$ and denotes the probability of damage to a building under extreme weather conditions.

Looking ahead, as the year goes on and the population increases, the frequency of extreme weather events will increase. The expression for the frequency of occurrence of extreme weather events in a year is as follows:

$$f(N, t) = f(N) \cdot (1 + d) \quad (20)$$

Where d is the percentage increase in the occurrence of extreme weather events in a year, where d is set to 0.1.

In general, the better the quality of a building, the less likely it is to be damaged by a disaster. As a result, both insurers and property developers consider the quality of the buildings built in disaster-risk areas. The factors we consider in relation to the quality of the building are the lack of care of the owner, the geographical location of the house, and the type of construction of the house.

$$\varepsilon(t) = \partial \cdot \frac{1}{O} \cdot \frac{1}{G} \cdot \frac{1}{T} \quad (21)$$

Among them, is the ∂ adjustment coefficient of the formula, which is O inversely proportional to the owner's lack of care, $\varepsilon(t)$ inversely proportional$G$ to the geographical distance of the house, and inversely $\varepsilon(t)T$ proportional to the building type of the house.

In summary, we obtain the profit optimization model of the insurance company after the optimization of Section 4 as follows:

$$W = \max [n \cdot x - n \cdot P(N.\varepsilon, t) \cdot y] \quad (22)$$

$$\text{s.t.}\begin{cases}\begin{cases}E(N)=\sum_{i=1}x_i f(x_i)\\ Var(N)=E[x^2]-\mu^2\end{cases}\\ \begin{cases}E(X)=\lambda\cdot\tau\cdot\left(1+\frac{1}{k}\right)\\ Var(X)=\lambda^2\left[\tau\left(1+\frac{2}{k}\right)-r^2\left(1+\frac{1}{k}\right)\right]\end{cases}\\ H=\begin{cases}H_L=\pi_L E(x),\pi_L=0.4,while\ 0\le\pi_L\le 0.4\\ H_H=\pi_H E(x),\pi_H=0.6,while\ 0.4<\pi_H\le 1\end{cases}\\ M=\mathrm{x}\cdot F\\ \begin{cases}y=E(x),while\ E(x)\ge M\\ y=M,while\ E(x)\le M\end{cases}\\ \eta=n_{\propto}/\mathrm{n}\\ A=\alpha\cdot n\cdot E(N)\\ \varepsilon(t)=\partial\cdot\frac{1}{O}\cdot G\cdot\frac{1}{T}\\ f(N,t)=f(N)\cdot(1+d)\end{cases}\end{cases}\tag{23}$$

3.2. Application of the model

Based on the above optimized profit optimization model of the insurance company, we consider four different qualities of housing structures, and the results obtained with time and population density are as follow in Fig. 3:

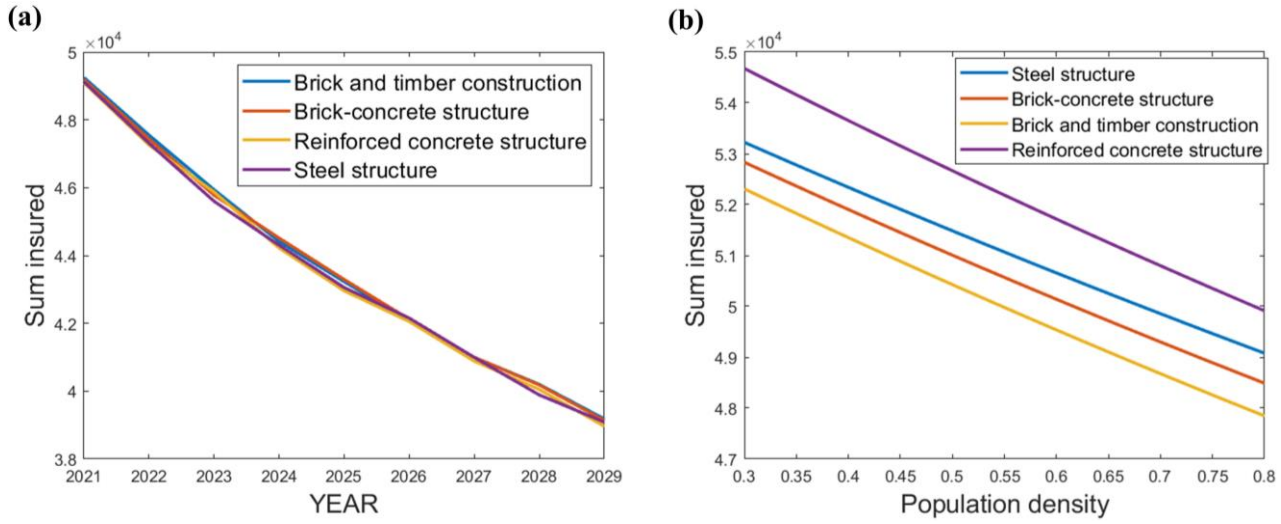


Figure 3. Change in the sum insured over time for the four housing types (a) and the effect of increasing population density on the sum insured (b).

As can be seen from the above results, the insurance amounts for all four types of houses show a decreasing trend as the number of years increases, which is due to the combined effect of the probability of extreme weather events and the increase in the probability of house collapses as the number of years increases. In terms of population density only, the insurance amount also shows a decreasing trend as the population density increases.

At the same time, the graph shows that over time, houses with reinforced concrete structures are less likely to be damaged by extreme weather due to their better quality, so the insurance companies will be willing to cover a higher amount of insurance than other houses.

Based on the above analysis, we will generalize the model based on the risk probability of extreme weather events and the impact of different building construction qualities.

We consider profit = 0, i.e., = $\mathrm{W}=\max\left[n\cdot x-n\cdot P(t)\cdot y\right]0$ as the critical condition, to determine whether the model is suitable for this one area. We have generalized the model to the world, and the location of the insurance suitable for establishment is shown in the following Fig. 4.

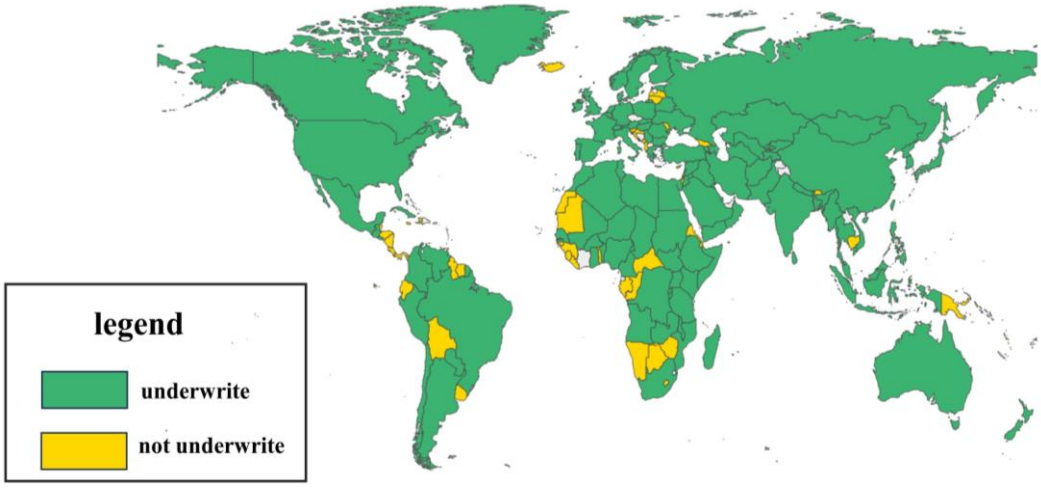


Figure 4. Insurance application

As can be seen from the above chart, the degree of inadequacy of insurance in coastal countries is much greater than that in landlocked countries, which may be due to the higher probability of extreme weather in coastal countries. It can also be seen from the graph that insurance companies are less likely to be willing to establish insurance in less economically developed areas, which may be due to the inferior quality of buildings in these areas.

4. Summary

In conclusion, our study presents an optimization model that effectively addresses the inherent tension between insurance company profitability and policyholder affordability, thereby promoting the sustainable development of property insurance. We highlight the scientific rigor and realism of our selected data, underpinning the credibility and practicality of our findings. However, our research also identifies areas for improvement, notably in streamlining the complexity of our models and further refining the building value evaluation process to encompass historical and social dimensions. Our contributions offer valuable insights and methodologies for enhancing the resilience of the insurance sector and preserving architectural heritage, with ongoing refinement crucial for maximizing their impact in real-world applications.

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