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Insurance, Development, and Conservation: Models Based on Time Series Forecasting and Recursive Forecasting Methods Summary

Jiahao Xin [1] and Huawei Huang [1,*]

[1] University of Manchester, Manchester, United Kingdom
* Correspondence: Huawei Huang, University of Manchester, Manchester, United Kingdom

Abstract: The natural environment is undergoing significant changes due to human activities, with extreme weather profoundly impacting various aspects of life. In response to increasingly frequent natural disasters, insurance companies and land developers require effective mathematical models to balance risk and reward. Meanwhile, communities need a quantifiable scientific approach to preserve properties of cultural, historical, or economic value. For the first question, we use the insurance client retention rate and the annual probability of extreme weather in Japan and the U.S. to build a time series forecasting model. By comparing future insurance retention rates and extreme weather probabilities with current homeowner insurance amounts, we develop a recursive forecasting model to predict future insurance price trends. For the second question, as land cost is the largest expense in real estate development, we analyze an undeveloped site in Hong Kong's Falling North area using data from the Environmental Protection Agency. Since the latest environmental assessment report is outdated, we recalculated pollutant concentrations and estimated an 8-year government treatment period. We then collected data on heavy rain, typhoons, land prices, and Hong Kong's insurance retention rate from relevant sources. Using a time series forecasting model, we project these factors over the next eight years and apply a recursive forecasting model to estimate future housing insurance prices. For the third question, we obtained historical data on sandstorms, extreme temperatures, tourist numbers, and revenue from the Forbidden City in Beijing. We forecast sandstorms, extreme weather, and tourist numbers over the next five years, then built a recursive forecasting model incorporating 2023 revenue data to predict future earnings. Finally, we proposed preservation strategies for historic buildings within the Forbidden City.

Keywords: time series forecasting; recursive forecasting; land environment assessment; conservation of historical architecture; insurance prices; insurance client retention rate

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1. Introduction

1.1. Restatement of the Problem

Based on understanding of the background information, our team identified the following problems in the problem statement that need to be addressed:

Build a mathematical model that can be used as a pricing reference for insurance companies and apply it to two regions on different continents where natural disasters are frequent (we chose the United States and Japan). Then, providing suggestions based on the results from model.

Adding more realistic factors, developing and improving the existing models, and using the new models developed to solve realistic land development problems. Here we take Hong Kong as an example.

Developing more on the basis of the existing models, so that the new model can predict the economic benefits of some famous places. Hence, it can provide a reference for community leaders or managers to give economically justified inputs to the planning of conservation programs.

Apply the model on a historical landmark (here we choose Forbidden City in Beijing) to get its economic value. Then, provide the relevant managers with a conservation recommendation based on the model's conclusions.

1.2. Our Work

To solve the problem above, we first created a basic mathematical modeling framework. Then, we integrated and analyzed natural disaster rates and insurance client retention rates in the U.S. and Japan. Using the analysis, we were then able to develop the underlying model through time series forecasting and recursive forecasting methods and make it possible to predict economically rational future pricing in the insurance industry.

Next, we added more realistic factors about Hong Kong to this pre-existing insurance model, especially considering the impact of land contamination on land development. Subsequently, still through time series forecasting and recursive forecasting, we obtained a new model applied to Hong Kong. This model can provide a business reference for land developers and insurance practitioners [1].

We then removed factors related to client retention from the first model, the insurance model, and added factors related to damage to historical landmark and the economic benefits of landmark. For a historical landmark, we chose the Forbidden City in Beijing. With the time series forecasting and recursive forecasting, the model can effectively predict the economic benefits of historical landmarks. These economic data will help the relevant managers to evaluate the input levels for landmark preservation.

In summary, the entire modeling process is illustrated in Figure 1:

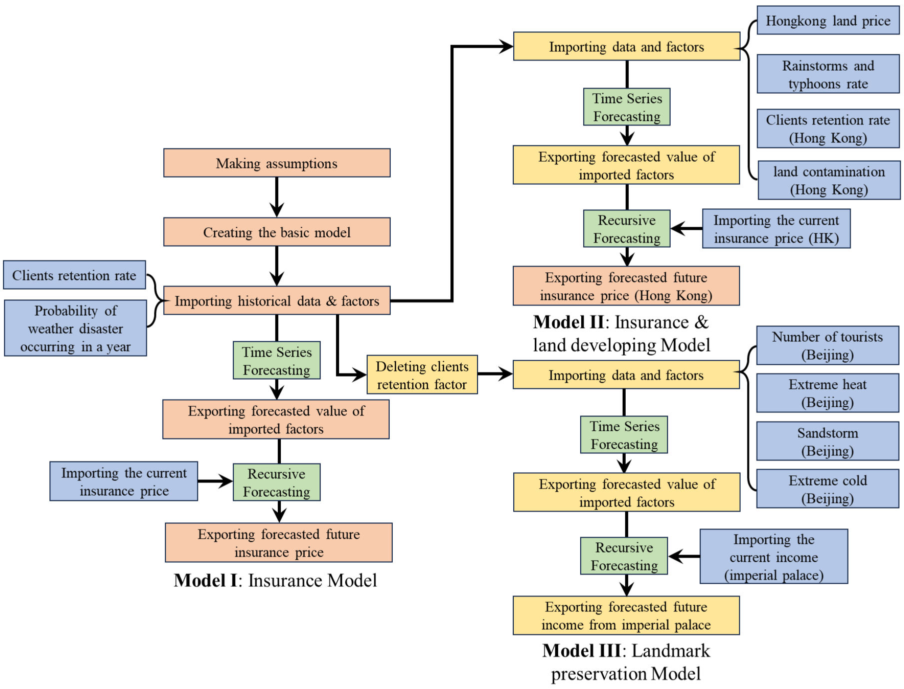

Figure 1. Model Overview.

2. Assumptions

Prior to solving the problem, we made the following assumptions.

1) Assumption 1: The increasing frequency of natural disasters is a common issue on all continents.

Justification: Global warming and other similar climate crises are an equally present problem for all regions of the world. Even though the manifestations and magnitude of these problems may vary in different areas, the trend toward gradual exacerbation should be the same.

2) Assumption 2: Both insurance companies and land developers seek to maximize profits.

Justification: Assuming that these firms operate in a profit-seeking and rational manner makes it more efficient and straightforward to predict the decisions they make in the face of problems. Moreover, our modeling is only meaningful if the firms operate in a commercially rational manner.

3) Assumption 3: No government interventions and public welfare policy in the research time.

Justification: Our model mainly compares and considers the impact of natural factors on these companies. However, government intervention from a public good perspective could force companies to make decisions that are contrary to commercial rationality. Therefore, our predictions can only be accurate and generalizable if we exclude these external factors.

4) Assumption 4: Assume the research data is accurate.

Justification: We assume that the data on climate change, environmental pollution, and corporate profits used in the study are accurate and not false. Therefore, our mathematical model will be valid.

3. Data Sources

The data sources used in this paper and building models are listed in Table 1.

Table 1. Data source.

Database Names	Websites
Global Natural Disasters Database	http://disaster.ncdc.ac.cn/#/root/view
Natural Disasters	https://ourworldindata.org/natural-disasters
Unusual Climate in Japan	https://www.data.jma.go.jp/cpd/longfcst/extreme_japan/index.html
From the 1st year of Heisei to today's disaster	https://www.data.jma.go.jp/stats/data/bosai/report/index_1989.html
Disasters Identified Each Year	https://www.data.jma.go.jp/stats/data/bosai/tornado/stats/annually.html
Past Significant Weather Events (1950s til now)	https://www.weather.gov/mob/events
Records of Land Sales	https://www.landsd.gov.hk/tc/resources/land-info-stat/land-sale/land-sale-records.html
Warnings & Signals Database	https://my.weather.gov.hk/sc/cis/warndb.htm
Historical Weather in Beijing	https://www.tianqi24.com/beijing/history202209.html
Insurance Indicators: Retention Ratio	https://stats.oecd.org/index.aspx?queryid=25441#

4. Notations

The key mathematical notations used in this paper are listed in Table 2.

Table 2. Notations used in this paper.

Symbol	Description	Unit
a_i	Insurance client retention rate (in year i)	
b_i	Extreme weather event rate (in year i)	
JPY_i	Insurance Price (Japanese Yen, in year i)	¥
USD_i	Insurance Price (US Dollar, in year i)	$

5. Model I: Risk Consideration in Disasters: Insurance Model

5.1. Infrastructure of the Model

Insurance companies can hedge risks and secure client retention by setting different insurance prices. Our most basic model is based on considerations and relations between insurance prices, risk and customer retention rate.

Firstly, through

$$(1 + (a_{i+1} - a_i)/a_i) \quad (1)$$

We will have the percentage change of the insurance client retention rate between year i and year (i + 1).

Then through

$$(1 + (b_{i+1} - b_i)/b_i) \quad (2)$$

We will have the percentage change of the extreme weather disasters rate between year i and year (i + 1). Therefore, by relates them and the insurance price in year i, using the Japanese yen as an example, together, a recommended price setting in the next year could be found by

$$JPY_{I+1} = (1 + (a_{i+1} - a_i)/a_i) \times JPY_i \times (1 + (\mathrm{b}_{i+1} + 1 - \mathrm{b}_i)/\mathrm{b}_i) \quad (3)$$

Introducing more factors and developing on this basic mathematical model leads to more accurate conclusions and predictions. Now, by tallying historical data and predicting possible disasters, we can use this model as a basis for evaluating the pricing strategies that U.S. and Japanese insurers should use.

5.2. Historical Weather Disasters Analysis

We build mathematical models and we choose America and Japan to analyze because the influence of natural disasters to these two areas were quite obvious.

The following data were imported: number of disasters, number of deaths due to extreme natural disasters, percentage of GDP affected by extreme weather and number of people displaced by disasters.

Figure 2 reflects that the US experienced a more variable trend which means in these 23 years changes and occurrences of extreme weather in the US were harder to predict. Precisely, we can conclude before 2019, the number of disasters in the US were fluctuated and it became stable after that. Meanwhile, Japan has experienced a less frequent change but more precipitous change. From 2022 to 2023, the number of disasters fell from 13 to 3.

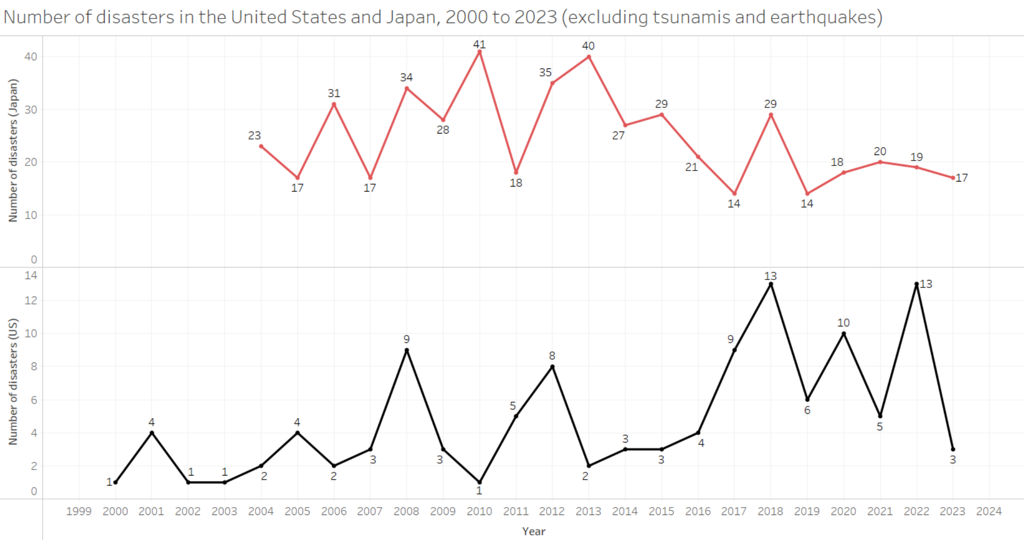

Figure 2. Weather-Related Disaster in the US and Japan, 2000 to 2023.

According to Figure 3, we can get the information about the number of deaths due to extreme natural disasters in the US and Japan. Comparing these two countries, we can see that the number of people died due to natural disasters in the Japan was larger than that in the US. It is obvious that in Japan there were plenty of people die in 2011, which was 19,976, much more than other years. In the US, the highest figure occurred in 2005, which was 1973, about 10 percent of the highest number in Japan. However, the trend was more fluctuate in the US than that in the Japan, which means it was more difficult to predict in these 23 years.

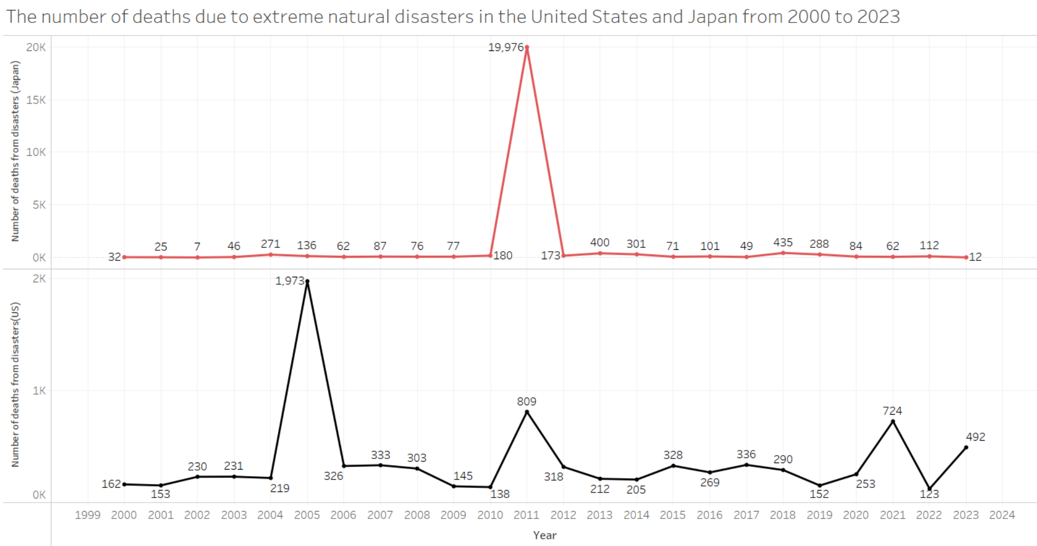

Figure 3. Deaths Caused by Extreme Natural Disasters in US and Japan, 2000 to 2023.

According to Figure 4, we can compare how extreme weather affected the economy in these two countries during these 23 years. We can still clearly see that the most damage situation happened in Japan was 2011, which was 3.410% damages. In other years, there were no quite obvious disasters in Japan. Notwithstanding, there were four particular economic shock in the US, selectively in 2005, 2012, 2017 and 2021. Therefore, we can sum up that Japan got more extreme shock in the economy but the US got more shocks in the economy during this period.

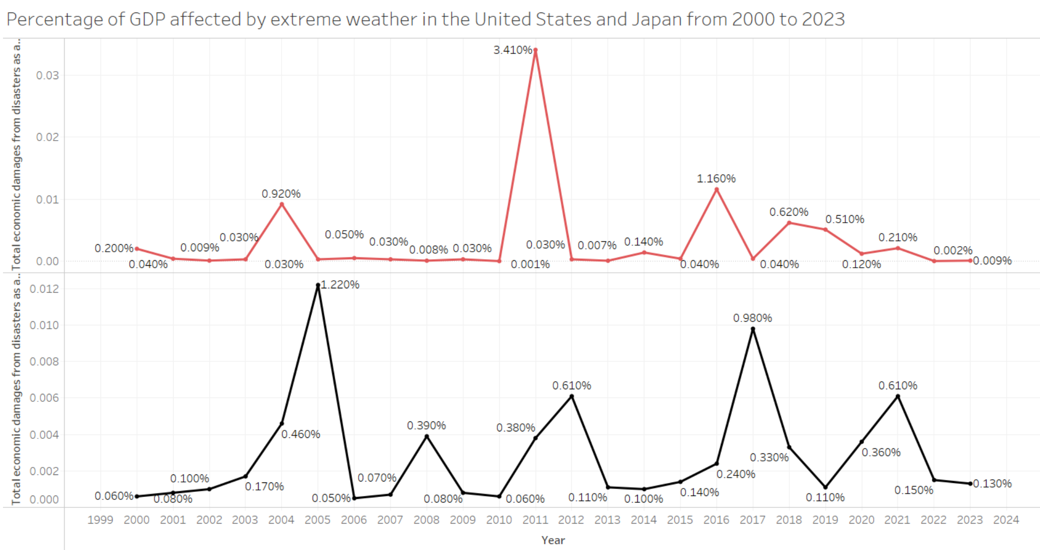

Figure 4. Percentage GDP affected by extreme weather in US and Japan, 2000 to 2023.

According to Figure 5, we can see that in Japan there were lots of people displaced by disasters in 2007 and 2016, selectively 40,688 and 23,991. in other years, except there were 5800 people die in 2004, the number of displaced people were nearly 0. In the US, homeless people due to disasters were much higher than that in Japan. There were 75,898 and 109,108 people displaced separately in 2001 and 2017. But the same point for these two countries was they both had two obvious horrible periods and other times were stable.

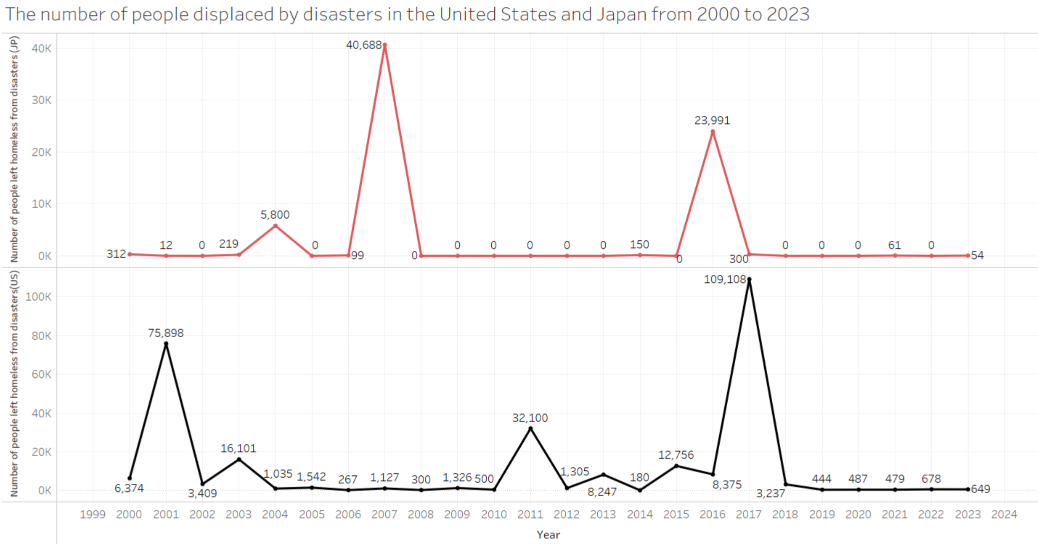

Figure 5. People displaced by disasters in US and Japan, 2000 to 2023.

To sum up, the number of disasters in the Japan were more than that in the US, so we may need more precautions and preservation and insurance in Japan. Also, we can guess that Japan may have better precautions awareness and medical systems to face disasters because people except 2011, the death rate in the Japan was more stable than that in the US. People displaced in Japan were less than that in the US as well. Additionally, the US had more fluctuated rate in GDP when it encountered extreme natural disasters. Therefore, a brief conclusion is, according to the model, Japan did better than the US when they both encountered the natural disasters during this certain period.

5.3. Forecasted Weather Disasters Analysis

Based on the model, we make a prediction on the number of extreme disasters in Japan and the US in the next 10 years. Figure 6 shows that although in the past few years, the number of disasters decreased gradually to a stable rate over time. Therefore, to conclude, Japan may experience a predictable time about disasters. In this case, it is easier for insurance companies to understand how many disasters may happen in a year and what they need to do to prepare.

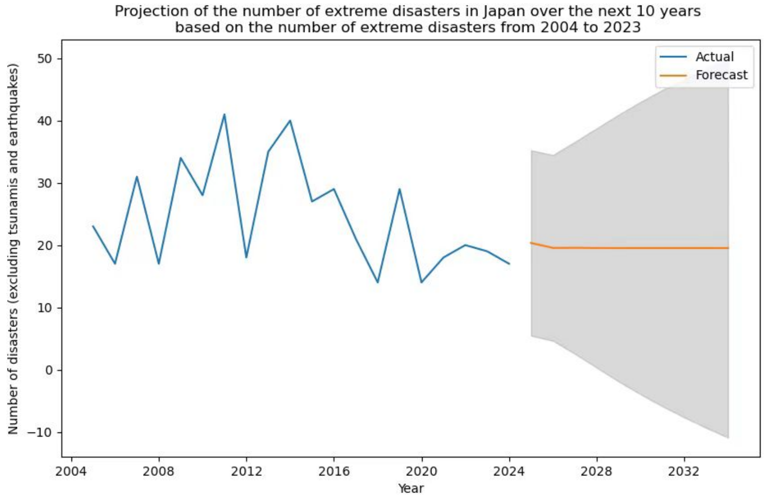

Figure 6. Projection of disaster number in Japan over the next 10 years.

Figure 7 shows that the number of disasters in the US in the past 2 decades demonstrated a quiet variable trend, and the trend became more and more changeful. Therefore, we may predict that in the next 10 years, this situation will maintain in the US. In some years, there may be more disasters than that in other years. Hence, it will be much more difficult for insurance companies to prevent and make the compensation policies. However, it is impossible for insurance companies to do nothing because this will let them loss plenty of customers and go bankrupt. In this case, the US companies may consider to limit the amount of compensation, make a detailed form to explained in the number of claims that can be made each year and the amount of compensation received to different disaster degrees.

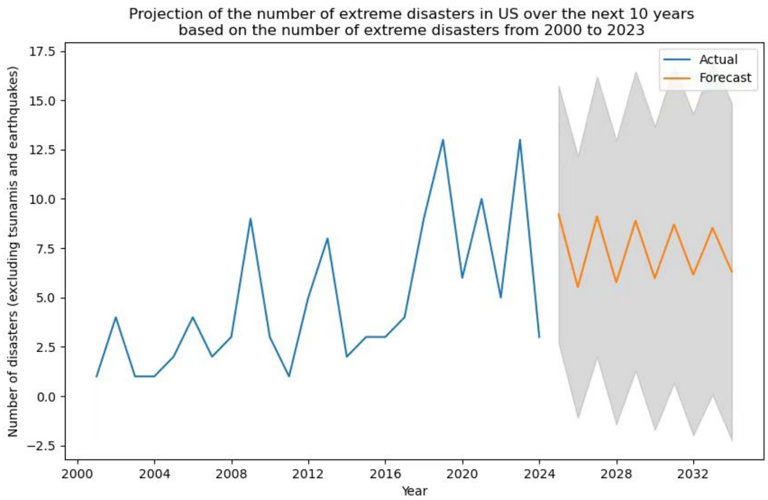

Figure 7. Projection of disaster number in US over the next 10 years.

5.4. Forecasted Insurance Price in the US and Japan

The above analysis based on the time series forecasting method plus present insurance prices can already be applied to the recursive forecasting method to arrive at economically rational future insurance prices.

First, Figure 8 concludes that insurance prices in the United States are dramatically cyclical over the next several years. This cyclical rise and fall is consistent with the cyclical climate disaster trends in the United States.

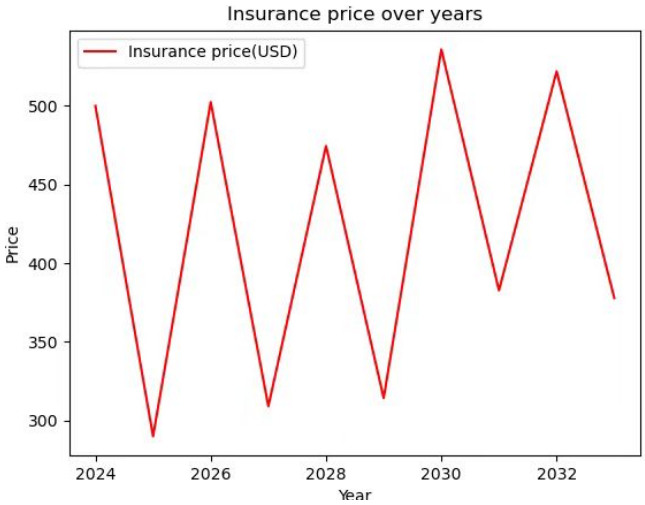

Figure 8. Projection of insurance price in the US over the next 10 years.

However, the same model predicts very different trends in insurance prices in Japan. Figure 9 reflects a very specific trend: insurance prices in Japan are steadily decreasing year after year. The reason behind the same algorithm yielding different results can be quite a valuable reference for the insurance industry, which I'll talk about in more detail in the next section.

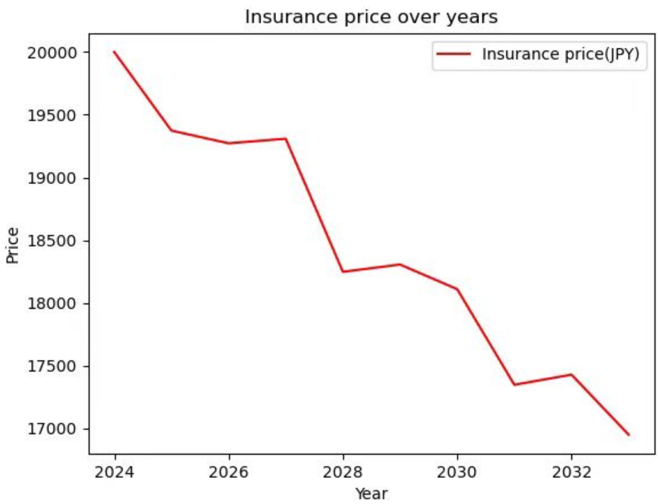

Figure 9. Projection of insurance price in Japan over the next 10 years.

5.5. Model I Summary: Advice Provided to the Insurance Industry

From the conclusions of the model, we find that natural disasters have a relatively pronounced periodicity. Therefore, insurers should underwrite in the window between two natural disasters to minimize losses.

The case of Japan provides an exception: even in countries with a high incidence of disasters, insurance prices may fall rather than increase due to a shrinking market brought about by, for example, aging, population decline, and so on. In this shrinking market, companies should take certain risks in order to continue operating. Otherwise, it is better to price and underwrite insurance based on the cycle of natural disasters.

As seen in the model, insurers' pricing strategies and market behavior are essentially entirely in accordance with commercial rationality and the occurrence of disasters. These elements cannot be artificially altered, and therefore, the commercial decisions of the insurance industry are difficult to influence by customers, property owners.

Therefore, based on the model, we can only recommend that property owners choose insurance companies with relatively low monopoly positions. These companies may have lower prices in order to compete in the market and may be more willing to take risks.

6. Model II: Land Developing Model

By developing the insurance model with the addition of land environmental assessment and other realistic factors, a new model can be obtained that will help land developers with their appraisals. In this section, because the data on land development in Hong Kong are relatively well established, we chose the relevant factors in Hong Kong for modeling.

6.1. Land Environmental Assessment

For developers, the development value of a land depends largely on its environment. Therefore, how long it takes to bring potentially contaminated land into compliance with environmental standards will be an important factor in the model [2,3].

We used data from polluted areas in the Kwu Tung North and Fanling North showed by the Figure 10 below.

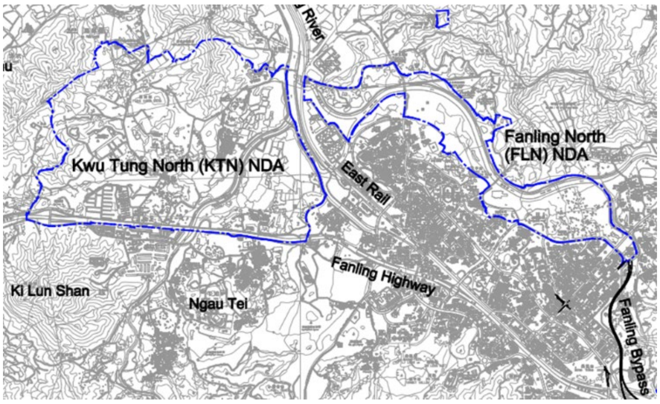

Figure 10. Map of Kwun Tung North and Falling North.

Here we highlighted the situation in Kwu Tung North in Figure 11, where has an average arsenic concentration of 398 mg/kg in soil. In contrast, the U.S. compliance standard is 0.39 mg/kg.

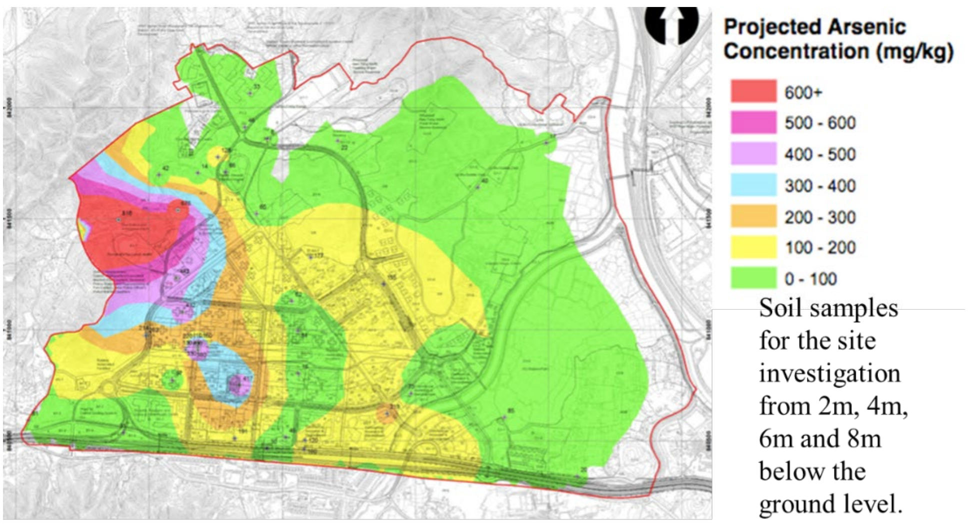

Figure 11. Arsenic Concentration (mg/kg) in Kwu Tung North.

If we assume a restoration rate of 50 mg/kg per year, then we can calculate how long it will take to reach compliance by following the steps below.

First, we need to calculate how much arsenic concentration needs to be reduced in total:

$$398\text{mg/kg} - 0.39\text{mg/kg} = 379.61\text{mg/kg} \quad (4)$$

We can then calculate how many years it will take by dividing the above result by the annual restoration rate:

$$(397.61\text{mg/kg}) \ / \ (50 \text{ mg/kg/year}) = 7.9522 \text{ years} \quad (5)$$

Therefore, it will take approximately 8 years to reduce the arsenic concentration to 0.39 mg/kg. Then we included this result to the model.

6.2. Forecasted Disaster Number and Unit Land Price in HK

Based on information reflected by Figure 12, we build the model to predict the number of Typhoon in Hong Kong. It is clear that from 2014 to 2023, there were two large up and down changes, but the second change became smaller than the first change. Therefore, we may predict that in the next few years, the number of Typhoon in Hong Kong will become more stable.

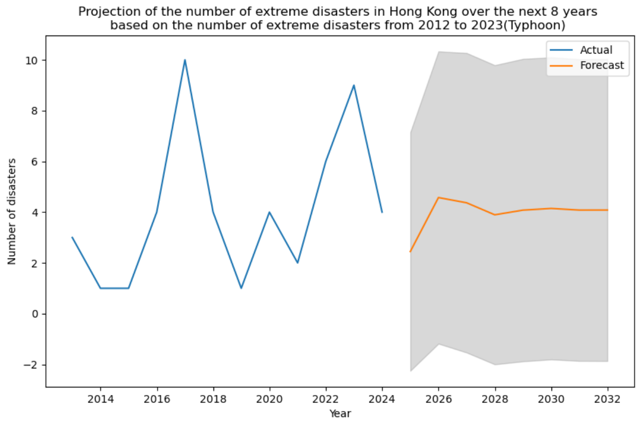

Figure 12. Projection of typhoon number in HK over the next 8 years.

Based on Figure 13, we make a prediction for another number of extreme disasters, rainstorm, in Hong Kong.

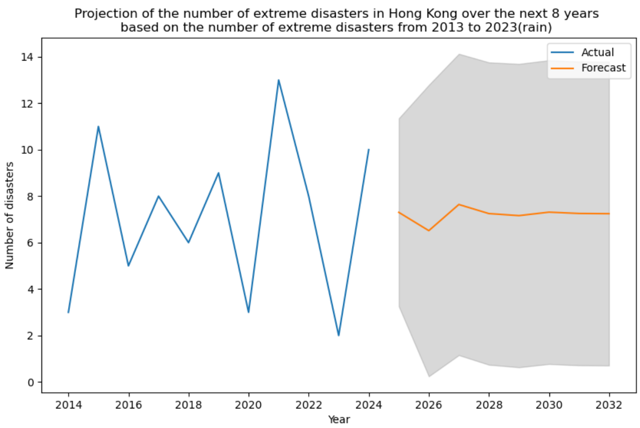

Figure 13. Projection of rainstorm number in HK over the next 8 years.

As Figure 14 shows, we predict the unit price of land in Hong Kong. Although, the trend varied from 2014 to 2023, the range of the change was not particular large. Hence, the unit price of land in Hong Kong will decrease in the next few years and then become more stable.

Figure 14. Projection of unit land price in HK over the next 8 years.

6.3. Forecasted Insurance Price in Hong Kong

According to this model, we can easily get the conclusion about the prediction of insurance price over years. From the beginning of 2024, it is obvious that there will be a rapid increase in the trend, and it will reach to the peak which will be about 13,500 HKD in 2026. Then, in the next following year, it will decrease, to some extent, a bit to approximately 11,000 HKD. After that, the insurance price will maintain in a stable rate which will be around 12,000 HKD, shown in Figure 15.

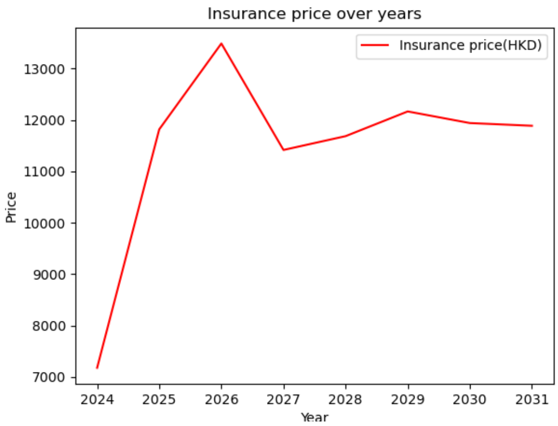

Figure 15. Projection of Insurance Price in HK over the next 8 years.

6.4. Model II Summary: Advice Provided to the Developers

Model II can help developers to clarify their thinking and choose the appropriate development cycle. The predictions from Model II indicate that development of land in areas with land contamination such as Kwu Tung North or Fanling North should be planned as far in advance as possible due to the long period of time required for decontamination.

In addition, due to high market demand, high population density, and the relatively high frequency of extreme weather events, land development in areas similar to Hong Kong may be subject to considerable insurance premiums.

In summary, developers in similar areas may choose to raise capital and hedge their risks through outsourcing or housing pre-sale models. Such a sales model would also help to keep the company running during the long land clearance process.

7. Model III: Conservation-Resources Balance Model

Deciding how much economic resources to invest in the preservation of historic buildings can often be a point of contention. To solve this problem, we removed the factor about insurance client retention from the insurance model, and added factors for climate disaster in Beijing and factors for Forbidden City income, using the Forbidden City in Beijing as a case study. In this way, the model is able to predict the future revenue of the Forbidden City and serve as a reference for decision makers when deciding the amount of resources to be invested [4,5].

7.1. Analysis on Model Results

Based on this model, we can clear see that from 1994 to 2023, the number of domestic tourists in Beijing had a steady upward trend though there was a decrease during 2020 and 2022, shown in Figure 16. Therefore, we can conclude that in the next decade, this trend will continue go up with a stable speed.

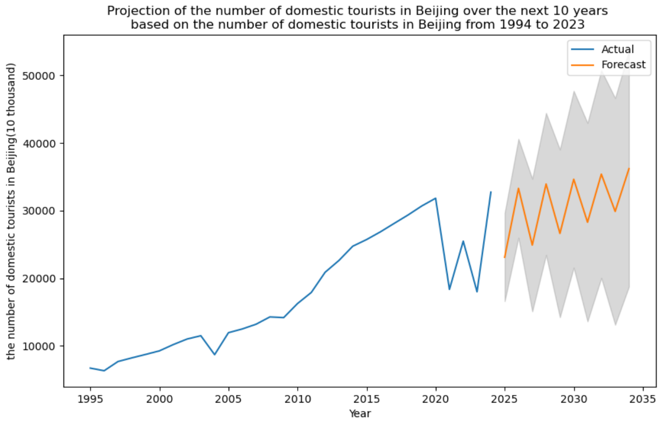

Figure 16. Number of domestic tourists in Beijing over the next 10 years.

According to Figure 17, we make a prediction on the number of occurrences of extreme low temperatures in Beijing based on historical data. It is obvious that from 2020 to 2023, the change formed a V-shape which went down to the lowest point and then went up rapidly. Hence, to sum up, in the next few years, it will drop first and the go up.

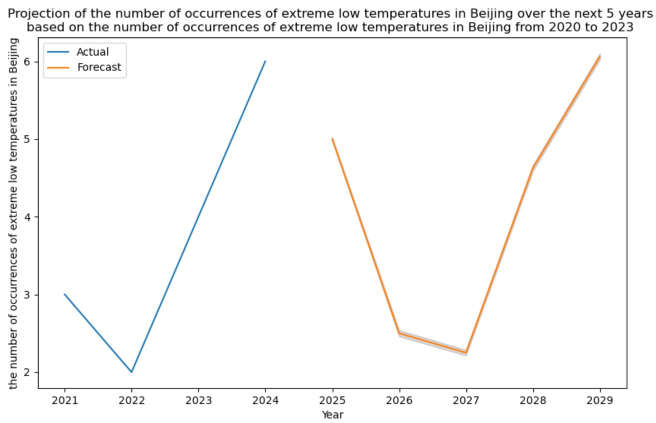

Figure 17. Number of extreme low temperatures in Beijing over the next 5 years.

According to Figure 18, we make a prediction on the number of occurrences of extreme high temperatures in Beijing. Comparing to the previous figure (extreme low temperatures in Beijing), it formed a U-shape. Hence, according to the historical information, we believe that in the future, the trend will not change a lot and approximately maintain stable.

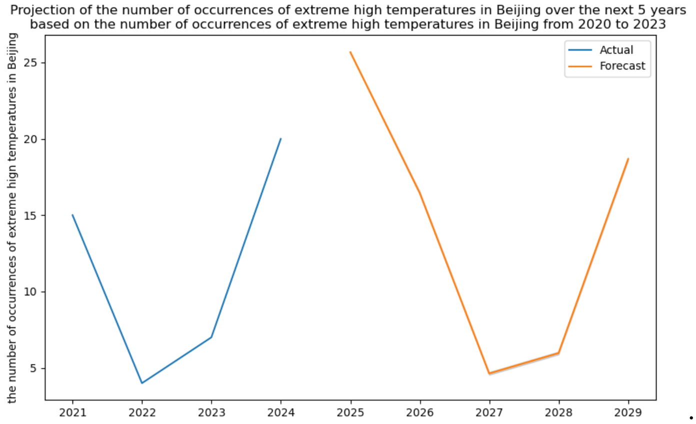

Figure 18. Number of extreme high temperatures in Beijing over the next 5 years.

The Figure 19 shows the projection of the number of occurrences of sandstorm in Beijing. From 2020 to 2023, there was a slow overall upward trend and the number reached about 40 in 2023. Hence, we ca predict that in the next few years the number will vary but in a quite stable rate.

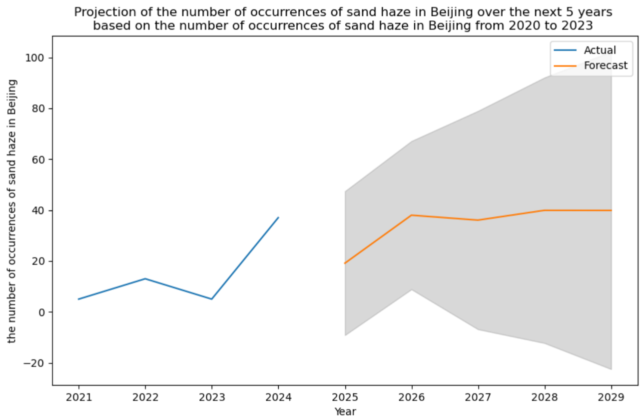

Figure 19. Number of occurrences of sandstorm in Beijing over the next 5 years.

Figure 20 will predict the income of the Forbidden City of the Ming and Qing Dynasties in Beijing. Starting from 2024, it will drop down and reach the lowest point (around 25,000) in 2026, the trend will go up but firstly in a slow rate and in a quite rapid rate.

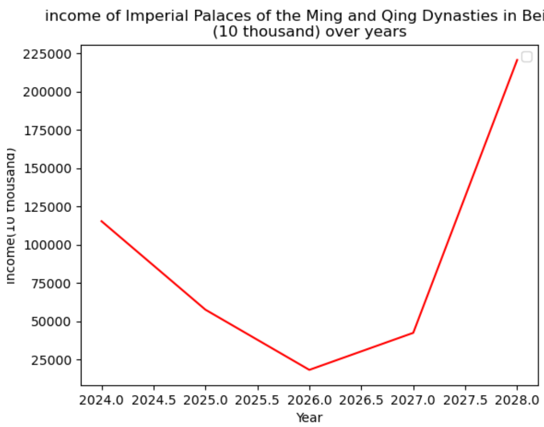

Figure 20. Forecasted income of the Forbidden City over the next 5 years.

7.2. Suggestion and Plan on Conservation of the Forbidden City

The Forbidden City, as a treasure of Chinese history and culture, is a world cultural heritage.

In order to protect the ancient architecture of the Forbidden City, we have developed the following planning program:

1) Regular inspection and restoration: Comprehensive inspections of ancient buildings are carried out regularly every year, focusing on the appearance of the buildings, walls, roofs, structures, foundations and other aspects. Problems are found to be repaired in time, and traditional restoration methods are adopted and traditional materials are used for restoration to maintain the traditional appearance and style of the buildings. During the restoration process, the principles and norms of ancient building restoration are strictly observed to ensure the quality and effect of restoration [6,7].
2) Pollution prevention and environmental protection: Measures have been taken to limit the number of tourists, control vehicle emissions and strengthen hygiene management in order to minimize pollution of ancient buildings. At the same time, trees and lawns are planted around the area to increase air humidity and reduce the impact of sandstorms. Through greening measures, the surrounding environment will be improved to protect the integrity and sustainability of the ancient buildings.
3) Training and personnel management: Training the staff of the Forbidden City to improve their conservation awareness and skills. The training includes basic knowledge of ancient building conservation, restoration methods, inspection techniques, hygiene management and other aspects [8]. Through training, improve the quality and skills of staff and strengthen the protection of ancient buildings. At the same time, the staff management system has been improved and a sound assessment mechanism has been established to ensure the stability and professionalism of the staff.
4) Protection publicity and cultural education: Strengthen the publicity on the protection of the ancient buildings of the Forbidden City, and raise public awareness of the protection of ancient buildings. Through a variety of media channels, such as television, radio, newspapers and magazines, and the Internet, the knowledge and significance of the conservation of ancient buildings are conveyed to the public. At the same time, by setting up exhibitions, lectures and other activities in the Forbidden City, more people can understand the significance and value of the protection of ancient buildings. Cultural and educational activities are carried out to guide the public to love and respect cultural heritage and to cultivate awareness of its protection.

In conclusion, through the comprehensive application of the above measures, the ancient architecture of the Forbidden City can be protected, so that it can be better protected, leaving more valuable cultural heritage for future generations. At the same time, it can also improve the public's attention and awareness of the protection of ancient buildings, and promote the inheritance and development of cultural heritage.

8. Conclusion

8.1. Model I and Its Result

The insurance model states that most of the time insurance prices will fluctuate cyclically with the trend of climate catastrophes, but in areas where the population is decreasing and the market is shrinking insurance prices tend not to be disproportionately affected by climate catastrophes. Insurance companies can use the model as a reference for their own pricing, and as a reference for operating in small markets, using the case of the Japanese insurance market.

8.2. Model II and Its Result

The model points out that insurance prices are undesirable for developers when there is a high incidence of climatic disasters, combined with the presence of contamination on the land. In order to address this issue, developers need more flexible business models to adapt to the fact that the market is characterized by long development cycles and high risk.

8.3. Model III and Its Result

The model can help decision makers invest economically responsible resources in preservation projects by predicting the future economic returns of historical buildings. However, the model takes more account of economic factors and less of cultural significance. Relying on the model alone is insufficient in practical decision-making.

9. Model Evaluation

In this essay, we use two different methods, time series forecasting and recursive forecasting, to build mathematical models. They both have advantages and disadvantages.

9.1. Strengths of Time Series Forecasting

1) It considers and involves the effect of time such as the change in seasons, trends and so on, especially when we analyze extreme disasters and make predictions;
2) It can capture the periodic pattern, it can get regular and periodic information such as every week, every month and every year. In our research, we use it to analyze the number of disasters occurring and changes during a given period;
3) It is able to deal with missing data. It can make predictions by filling in missing values through methods such as interpolation or padding. Sometimes, in our modelling process, collecting complete data is a very difficult task, so we need to consider a model that can solve this problem.

9.2. Weaknesses of Time Series Forecasting

1) It has a relatively high requirement for historical data. If there is a lack of historical data and some errors, it will make an inaccurate prediction;
2) It has a relatively high requirement for stationarity of data which means the mean and variance of the data do not change over time.

9.3. Strengths of Recursive Forecasting

1) It has a high flexibility. It can adjust and change based on the characteristics of data and specific questions in order to make different predictions according to different requirements. In this case, we need to deal with and make the predictions for some difficult data such as insurance price over year.
2) It can deal with complicated data and model. It can be used in some complicated models such as large-sized financial data, neural network and so on to capture non-linear relationship in order to increase the accuracy of prediction.

9.4. Weaknesses of Recursive Forecasting

1) It is sensitive to original data which means it depends highly on the choice of original condition. Different original conditions may result different prediction results. For example, when we analyze the data for insurance companies, if we choose the factors or data, we may get a quite unsatisfactory result.
2) It is easy to get overfitting issue. Recursive prediction method tends to overfit training data, which will result in poor prediction effect on new data.

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