Study on China’s Earthquake Prediction by Mathematical Analysis and its Application in Catastrophe Insurance

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Abstract. The purpose of this paper was to improve catastrophe insurance level. Firstly, earthquake predictions were carried out using mathematical analysis method. Secondly, the foreign catastrophe insurances’ policies and models were compared. Thirdly, the suggestions on catastrophe insurances to China were discussed. The further study should be paid more attention on the earthquake prediction by introducing big data.

1. Introduction
A disaster is a serious disruption of the functioning of the society. Catastrophe includes the natural disasters such as earthquakes, floods and hurricanes. China is located between two of the world's major seismic belts which would bring earthquake. There are the Yangtze River and the Yellow River, which may bring floods[1]. In addition, many typhoons are formed in Pacific Ocean near South China sea. These catastrophe events would cause serious losses. Then insurance is an important method to protect human safety or financial loss. But these low-probability, high-cost catastrophic events are generally excluded from standard hazard insurance policies. Therefore catastrophe insurance is introduced hedge against these catastrophe risk[2].

In China, the Great Tangshan Earthquake in 1977 killed over 240,000 people and caused 5.4 billion in direct economic losses. The Wenchuan earthquake in 2008 killed over 69,000 people and caused 845.1 billion in direct economic losses. The 2010 Yushu earthquake killed over 2,200 people and caused over 800 billion in direct economic losses. The percent of losses from catastrophes covered by insurers in China was only 0.43%[3]. In recent years, the earthquake’s prediction has attracted more attention with the help of mathematical analysis. This study would improve our catastrophe insurance level.

2. Earthquake prediction using mathematical analysis
Mathematical analysis allowed earthquake predictions using different models or functions based on the history data[4,5]. Then the catastrophe insurance would reduce their losses by increasing premiums when the probability of catastrophic incident’s occurrence was high[6]. The different mathematical analysis methods were shown below to predict the earthquake’s interval time, frequency and location.

2.1. TREND FUNCTION and interval time
TREND FUNCTION could return values along a linear trend using the method of least squares. The history y’s value and x’s value should be known. The relationship should be y=mx+b. Then the new x-values could return corresponding y-values.

| Table 1. The history earthquakes’ interval times from 2012-2017 |
|---------------------------------------------------------------|
2. The predictive interval time is 0.61 based on the data from 2012 to 2017. TREND(B2:B46)=0.61. The predictive interval time is 0.51 based on the data from 2013 to 2017. TREND(B7:B46)=0.51. The predictive interval time is 1.95 based on the data from 2014 to 2017. TREND(B23:B46)=1.95. The predictive interval time is 2.72 based on the data from 2015 to 2017. TREND(B31:B46)=2.72. The predictive interval time is 1.81 based on the data from 2016 to 2017. TREND(B44:B46)=1.81.

Actually, the next M=5.7 earthquake happened on September 9, 2017 in Xinjiang Uygur Autonomous Region. In these results, the first predictive interval time, 0.61 month, was the most correct result. This first result’s reference data numbers were largest. Then the more data, the more accurate prediction[7]. Therefore, this prediction could be used to predict the next dangerous earthquake’s time table.

2.2. FORECAST FUNCTION and earthquake number

Figure 1: The earthquake location on September 9, 2017 www.ceic.ac.cn

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FORECAST FUNCTION could return values using linear trend regression. This predicted value was a y-value for a given x-value. The known values were existing x-values and y-values. This function could be used to predict future trends.

| Year | Number of Earthquake |
|------|----------------------|
| 2012 | 6                    |
| 2013 | 16                   |
| 2014 | 8                    |
| 2015 | 4                    |
| 2016 | 8                    |

According to FORECAST FUNCTION, the predictive number of earthquake was 6 based on the data from 2012 to 2016. FORECAST(2017, B2:B6,A2:A6)=6. According to this calculation, there would be 6 earthquakes whose magnitude was over 5 in 2017. There had been 3 earthquakes happened in 2017 from June to August. In the last four months, there would be other 3 earthquakes.

![Figure 2: The earthquake happens from September to December](image)

Actually, there were 5 other earthquakes happened in China Mainland in the last four months. Therefore, this mathematical analysis method could be used to predict the number of earthquake every year. This would be quite useful to insurance company to regulate rate[^8].

2.3. Trendline and location
There were six trendline to predict the location’s longitude and latitude based on a chart data. A linear trendline was used with simple linear data sets. A logarithmic trendline was a best-fit curved line that was most useful when the rate of change in the data increased or decreased quickly. A polynomial trendline was a useful curved line when data fluctuated. A power trendline was a curved line when compare measurements increased at a specific rate. An exponential trendline was useful when data values rose or fell at increasingly higher rates. A moving average trendline smoothed out fluctuations to show a trend clearly. Then the trendlines’ results were compared as shown below.
Figure 3: Six trendlines based on the earthquake location (x:latitude; y:longitude)

Actually, the next M=5.7 earthquake happened in Xinjiang Uygur Autonomous Region, whose east longitude was 42 and north latitude was 83. Then the most correct graph was Moving Average. Therefore, this mathematical analysis method could be used to predict the earthquake location. Different models or functions would lead to different results, so mathematical analysis should be studied further.

3. Catastrophe insurance policy

Compared with Chinese catastrophe insurance policy, foreign counties’ was more advanced. Many countries had established earthquake insurance systems in the 20th century. There were mainly three models including government-led model, market-led model and mixed model. The government-led model had high insurance capability but low financing capability. The market-led model had high financing capability but low insurance capability. The mixed model had relative high insurance capability and financing capability, which was applied in many foreign countries such as New Zealand, Japan and Turkey.

Table 3. Risk dispersed mechanism of EQC (billion NZS).

| disaster losses | Risk dispersed mechanism. |
|-----------------|--------------------------|
| <0.2            | Disaster losses will be paid by EQC. |
| 0.2-0.75        | Disaster losses (40%) will be paid by reinsurance company. The others will be paid by EQC (<0.2 billion NZS) and reinsurance company (< 0.13 billion NZS). |
| 0.75-2.05       | Layer reinsurance. |
| >2.05           | Disaster losses will be paid by the Natural Disaster Fund and government. |

New Zealand was located between Pacific plate and Australia plate. Earthquake and War Damage Act was passed by the New Zealand Parliament in 1944. The Earthquake Commission (EQC) was established in 1945 as the Earthquake and War Damage Commission. Earthquake Commission Act was passed in 1993. EQC is the core department of earthquake insurance system whose funds were coming from fire insurance. The risk dispersed mechanism was as shown in Table 3 using.
Christchurch earthquake (6.3 M) severely damaged New Zealand's second-largest city in 2011, killing 185 people on 22 February. EQC's reinsurance cover was already in place, so EQC and reinsurance company would be liable for earthquake losses. In addition, the New Zealand government collected NZ$ 26.6 million by issuing Earthquake Kiwi Bond.

Japan, located between Pacific plate and Eurasian plate, suffered earthquake disaster heavily. The 1964 Niigata earthquake led to Japan's current system which was unique in its cooperation between private non-life insurance companies and the national government. The Law Concerning Earthquake Insurance was made and Japanese Earthquake Reinsurance (JER) was established in 1966. Great Hanshin earthquake happened in 1995 leading to the earthquake emergency response. JER was the core department, which was responsible for connecting the government and market. Munich Reinsurance Company issued $300 million catastrophe bond in 2008 on behalf of Japanese cooperative Zenkyoren. The insurance rate and premium scale were obtained using mathematical analysis. The earthquake (9.0 M) and tsunami struck Japan heavily in 2011. The reinsurance companies would be liable for hundreds of millions of dollars. Japanese government bond for reconstruction were also issued in 2012.

Figure 4: Seismic hazard zones of Turkey

Turkey was located in North Anatolian Fault. The Reinsurance Monopoly Law was passed in 1927 to regulate the insurance activities. Milli Re, reinsurance company for earthquake risk, was established in 1929. Turkish Catastrophe Insurance Pool (TCIP) was launched in 2000, which brought mandatory earthquake insurance scheme according to seismic hazard zones. These zones could be divided using mathematical analysis\cite{11}. TCIP appointed U.S. RE Corporation with its Turkish partner to place reinsurance for the Pool’s earthquake risk in 2011. The earthquake (7.2 M) caused 20 billion dollars in direct losses. The TCIP, which was funded by insurers and backed by the World Bank and the Turkish government, retained the first $80 million of losses from an earthquake and transferred excess losses to the international reinsurance markets.

4. Chinese current catastrophe insurance

There were different stages in Chinese catastrophe insurance. For example, China’s earthquake insurance system had three stages. In the first stage, policies of catastrophe risk insurance were formulated by government in 1952, which continued to 1959. In the second stage, the insurance business was resumed in 1979 after Cultural Revolution. Insurance Law of the People's Republic of China was published in 1995, which didn’t include catastrophe insurance. In the third stage, the China Insurance Regulatory Commission made policies on catastrophe insurance more flexibly from 2000.

Hua’an Insurance launched a property and casualty insurance product covering earthquake liabilities in 2008, which had been well received in piloted cities such as Guangzhou and Tianjin. Insurance Law of the People's Republic of China was revised after Wenchuan Earthquake, in which the earthquake insurance was encouraged and supported in 2009. Chinese Comprehensive Disaster Reduction in the 12th "Five-year Plan" was published in 2011, in which the earthquake insurance should paid more attention for higher proportion of disaster loss. A proposal on establishment of earthquake insurance was submitted on Chinese People's Political Consultative Conference in 2012.
Ningbo’s catastrophe insurance would take effect officially next year after 3 years’ test from 2015 to 2017.

The percent of losses from catastrophes covered by insurers in Wenchuan Earthquake was much lower than 40-50% in America and 20-25% in Europe. This problem would be solved with the government’s support and mathematical analysis’s introduction.

5. Conclusion
Firstly, mathematical analysis could be used to regulated the catastrophe insurance’s rate. Secondly, more advanced market in foreign counties had different content divided using mathematical analysis. Thirdly, Chinese catastrophe insurance could be improved by government’s support using mathematical analysis. The big data would be used in catastrophe insurance to make the insurance rate more reasonable. With the development of social undertakings in 13th Five-Year Plan, China’s Insurance System would be improved further more to increased the safe level of our society.

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