How Much Difference in Earthquake Risk among China's Areas: A Study based on Pricing a Seismic Catastrophe Bond

JDIM

Journal of Digital Information Management

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ABSTRACT: *According to China's earthquake magnitude data from 1970-2009, we employed the extreme value distribution model to analyze the difference of annual maximum magnitude between China's major earthquake-prone provinces. By a stochastic simulation method, we give an example of pricing catastrophe bonds in earthquake-prone areas. It shows that the potential risk varied widely in different regions. As a conclusion, we suggest establishing a multi-level seismic risk financing mechanism, and it should be established in some special areas firstly.*

Subject Categories and Descriptors: [I.3.5 Computational Geometry and Object Modelling]; [I.4.10 Image Representation]: Statistical

General Terms: Risk Management, Seismic structures

Keywords: Earthquake risk monitoring, Seismic Catastrophe Bond

Received: 5 September 2022, Revised 21 November 2022, Accepted 12 December 2022

Review Metrics: Review Scale: 0/6, Review Score: 4.75, Inter-reviewer consistency: 80.4%

DOI:10.6025/jdim/2023/21/1/18-23

1. Introduction

As an extreme event, earthquake has low-probability but relatively huge economic loss. China is one of the countries suffering most serious earthquake disasters. Since 1900, the number of earthquake deaths is up to 550,000 in China, accounting for 53% of the world. Deaths caused by earthquake account for 54% of that caused by natural disasters.

Recently, Earthquakes in Wenchuan, Sichuan Province (2008) and Yushu, Qinghai Province (2010) make the issue of catastrophe risk management be placed in front of the researchers and policy makers. The compensation and reconstruction of the earthquake are mainly dependent on the government in China. On the other hand, the growing China insurance market and capital markets did not play an important role in catastrophe risk financing. Learning from the experience of developed countries, it is urgent to establish a seismic risk financing mechanisms to compensate the losses.

The indemnity for losses mainly relies on the reinsurance in developed countries. Because of the increasing losses in earthquake, it seems that the underwriting capacity of reinsurance companies is inadequate. Catastrophic insurance risk securitization is a kind of financial insurance innovation. Especially, catastrophe bonds can provide extra capacity by transferring risk to capital markets. So, it is used widely by catastrophe insurance agencies.

The development of the earthquake insurance in China is imperfect. Earthquake catastrophe bond can effectively improve China's insurance industry underwriting capacity, and it has broad application prospects. In June 2006, the State Development Bank, the Swiss Re and Munich Re issued bonds based on catastrophe losses, It is the first attempt to issue China's CAT bonds. However, some problems still should be discussed. Some scholars support to issue a nationwide catastrophe bond, to facilitate a greater range of indemnity for losses; While other scholars tend to support catastrophe, bonds issued by administrative divisions independent. Based on the literature [1], we do the following contributions:

• Using extreme value theory, we build the maximum magnitude model for China's earthquake-prone provinces, and compare the probability of a moderate earthquake and strong earthquake among different provinces;

• According to the same payment conditions, we use stochastic simulation method to calculate the magnitude triggered catastrophe bond prices in different seismic regions in China. We find that the level of bond prices is a comprehensive reflection of the overall seismic risk. The result also demonstrated that the seismic risk and losses in the China are imbalance in regions.

2. Catastrophe Bond Pricing Theory

The definition and classification of catastrophe bonds

The catastrophe bond is a new financial instrument. It makes the disaster losses, which is covered by the insurance market, be transferred to capital markets. The hedger (e.g., the reinsurer) pays an insurance premium in exchange for a coverage if a catastrophic event occurs in special time; and many investors purchase this insurance-linked bonds for cash. The total amount (premium + cash proceeds) is directed to a tailor-made fund, which is called a special-purpose vehicle (SPV). It issues the catastrophe bonds to investors, as well as purchasing safe securities as Treasury bonds. Therefore, investors hold nature-linked assets whose cash flows (coupons and/or principal) are contingent on the risk occurrence. If the covered events happen during the risk-exposure period, the SPV compensates the firm and there is full or partial forgiveness of the repayment of principal and/or interest. If the defined events do not occur, the investors receive their principal plus interest equal to the risk-free rate plus a risk-premium. The purpose of the issue of catastrophe bonds is to provide a reliable source of funding for possible future large catastrophe losses and improve the insurance company underwriting capacity for catastrophe risks.

From the perspective of insurers, catastrophe bonds to expand the insurer's underwriting capacity in China, involving a specialized catastrophe insurance and do not affect its solvency, the insurer is the biggest beneficiaries of the catastrophe insurance risk securitization.

From the investor point of view, catastrophe bonds are high-risk, high-yield financial products involved are institutional investors. Other products of this product and capital market is small, adding a small amount of catastrophe securities products in the portfolio can improve the efficiency of the portfolio.

The issuer of catastrophe bonds is the insurance company who underwrites catastrophe risk. The main issue is the underwriting loss of insurance companies, including potential property damage and personal injury. To assess the size of the earthquake risk accurately, such as the geological structure of the region, the seismic intensity and the internal structure of a particular region should be considered. But it is quite complex to explain how these factors results in huge earthquake.

Accordance to the trigger event, catastrophe bonds have three kinds: Loss-Trigger type, which pay for underwriting loss if the insured loss is excess a given limit; Index-Trigger type, which pay for underwriting loss if the entire industry loss index is excess a given limit; Parameter-Trigger type, which pay for catastrophe loss if certain physical parameter of the disaster intensity exceeds a predetermined range. Loss-Trigger type has the minimum of basis risk, which is the random variation of the difference between the hedge contract payout and the actual loss experience of the subject portfolio. However, it is a long time to confirm catastrophe losses. For bond investors, the damage assessment has higher moral risk. Parameter-Trigger type is opposite. It is attractive to investors for lower moral risk, However, insurance companies dislike to issue this type of bonds, for the concerns of the basis risk. Index-Trigger type is a compromise between the above two. Furthermore, index-based financial instruments bring transparency and efficiency to both sides of risk transfer, to investor and hedger alike. So, most of catastrophe bonds which are issued in foreign countries are of the trigger type.

But in China, there are still some obstacles to apply the catastrophe bonds in risk financing. Firstly, few of insurance company can underwrites the earthquake risk. The indemnity for losses still needs the government support. Secondly, the assessment of earthquak-e losses is still immature, For Index-Trigger type bonds, industry loss index is not existed yet. Therefore, Parameter-Trigger type bonds is a more realistic choice for China.

3. Research on pricing the catastrophe bond

The systematic study of the catastrophe bond pricing theory began in the mid-1990s. Cummins and Geman [2] proposed a general catastrophe bond pricing formula in the continuous trading and no-arbitrage conditions; Vaugirard [3] using Monte Carlo simulation method to study the catastrophe bond prices under Stochastic Interest; Burnecki [4-5] improved Cummins and Geman [2] arbitrage pricing model, the no-arbitrage price of a zero-coupon catastrophe bonds and interest-bearing catastrophe bonds. Litzenberger [6] to calculate the indemnity loss rates for the Frechet and stable Levy distribution catastrophe bond prices. Briys [7] assumed catastrophe loss index follows a geometric Brownian motion, and the market has no arbitrage opportunities, then concluded the expression of a catastrophe bond prices. Morton[8] improved and developed of a the LFC catastrophe bond pricing model. Cox [9] built the catastrophe bond pricing model based on the theory of equilibrium pricing. Wang [10] developed the LFC model to improve the computaciency by the probability transforming. Lee and Yu [11] considered moral hazard and basis risk, and proved catastrophe bonds can effectively reduce the risk of reinsurance basis. Cummins [12] provided a method to measure financing efficiency of different catastrophe financing products. Using seismic data in Mexico triggered catastrophe bonds, Wolfgang [13] proved a catastrophe bond tool with the catastrophe reinsurance can reduce the cost of risk transfering and default risk.

The representative articles in China include Li Yongquan [14], Han Tianxiong [15], Li Yong [16], Tian Ling [17], Shi jianxiang [18]. But none of them focus on the pricing of catastrophe bonds and empirical research.This article will research the earthquake risk in a different seismic zone bonds based on the cross-section data.

4. The Distribution For China's Seismic Area

The distribution of Earthquake hazard

Fig.1 shows the recorded earthquakes over 7 epicenters from 2300 BC to 2000 AD in China. We can easily find that strong seismic hazards in China are mainly distributed in several regions: Taiwan, China, North China, Northeast, three in Sichuan, Yunnan, Qinghai and Shanxi, Xinjiang and Tibet. This rough division also took into account such earthquake differences in population density and the economic development. Thus the basis risk of catastrophe bonds should be considered, because of the different geological conditions and population, the economic situation. Simply thought, such as "one size can fits all", issue a single cat bond is inappropriate. So, how much are the potential risk in the different areas? This article intends to employ the extreme value model to analyze earthquake risk, and then answer this question.

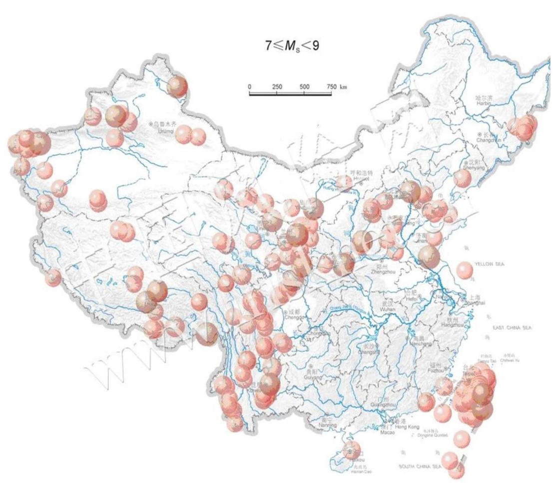

Figure 1. The distribution of earthquake above Ms. 7.0 in China (2300 B.C.-2000)

The probability distribution of earthquake magnitude in a region is inconclusive, but several earthquakes occur each year a certain place, If it is assumed that earthquake occurrence is independent and identically distributed, then one of the largest earthquake the magnitude of extreme value distribution to describe. According to Fisher-Tippett-Gnedenko Theorem,if is a series of i.i.d extreme value sequence,that is to say

$$M_n = \max\{X_{1n}, X_{2n}, \cdots, X_{mn}\} \quad (1)$$

It follows a extreme value distribution asymptotically:

$$\Pr[\frac{M_n - b_n}{a_n} \le z] \to G(z) = \exp\{-[1+\xi(\frac{z-\mu}{\sigma})]^{-\frac{1}{\xi}}\} \text{ for } n \to +\infty \quad (2)$$

Both a_n and b_n are Standardized coefficients,if M_n take the appropriate dimension,we can have a_n = 1and b_n = 1,The distribution of magnitude is just in the case. Here, ξ is a structure parameter. According to Fisher-Tippett-Gnedenko Theorem, If ξ > 0, $G(z)$ is known as extreme value distribution of type II(also called Fréchet distribution); If ξ < 0, is known as extreme value distribution of type I(also called Gumbel distribution). However, if ξ > 0, we can define equal to the limit when $\xi \to 0$. In our model, follows Gumbel distribution in many provinces. But it also follows Fréchet distribution in some areas, such as Fujian Sichuan and Beijing-Tianjin-Hebei region (BTH).

As is shown in Table 1, μ and σ are referred to the location parameter and scale parameter. The distribution use three parameters (μ and σ) to depict the shape of the three different types of extreme value distribution, however, here we are more concerned about the tail of the distribution of extreme value distribution. Tail probability of the distribution characterizes the probability of occurrence and severity of the strong earthquake. And theoretical research related to the extreme value theorem can refer to the literature [20].

The empirical results of the extreme value distribution

The earthquake's epicenter location and magnitude data can be gathered from the earthquake catalog data, we can extract a region in the 1970-2009 annual maximum magnitude data can access from our seismic network.

Province	Location	Scale	Shape	Mid Prob （Ms6-7）	Str Prob （>Ms7）
Taiwan	6.4111	0.5238	-0.1582	62.5276%	25.1726%
Fujian	4.6318	0.3677	0.1670	4.1321%	1.2544%
Sichuan	5.05632	0.6368	0.0235	15.6751%	5.1099%
Yunnan	5.6600	0.7053	-0.1682	35.7475%	9.6397%
Xinjiang	5.7110	0.4782	0.0211	35.2088%	7.0115%
Tibet	5.8721	0.5973	-0.2872	48.7784%	6.3676%.
BTH	5.0467	0.6031	0.09188	14.7311%	5.7014%
Qinghai	5.3902	0.6673	-0.0741	25.4027%	6.7704%
gansu	4.7617	0.5715	-0.2385	4.6280%	0.001125%
Neimeng	4.2634	0.2248	0.6943	5.8624%	3.8592%
Greece	5.6471	0.3833	-0.2110	30.0244%	1.5462%

Table 2. Parameters and Tail Probability of Models

Then use the theory of extreme value distribution can be fitted to the three extreme value distribution parameters for each region the largest magnitude. And then in different parts of probability in the tail of the strong earthquakes of varying degrees within one year, the results are shown in Table 1.

Province	*Location*	*Scale*	*Shape*	*Mid Prob (Ms6-7)*	*Str Prob (>Ms7)*
Taiwan	*6.4111*	*0.5238*	*-0.1582*	*62.5276%*	*25.1726%*
Fujian	*4.6318*	*0.3677*	*0.1670*	*4.1321%*	*1.2544%*
Sichuan	*5.05632*	*0.6368*	*0.0235*	*15.6751%*	*5.1099%*
Yunnan	*5.6600*	*0.7053*	*-0.1682*	*35.7475%*	*9.6397%*
Xinjiang	*5.7110*	*0.4782*	*0.0211*	*35.2088%*	*7.0115%*
Tibet	*5.8721*	*0.5973*	*-0.2872*	*48.7784%*	*6.3676%.*
BTH	*5.0467*	*0.6031*	*0.09188*	*14.7311%*	*5.7014%*
Qinghai	*5.3902*	*0.6673*	*-0.0741*	*25.4027%*	*6.7704%*
gansu	*4.7617*	*0.5715*	*-0.2385*	*4.6280%*	*0.001125%*
Neimeng	*4.2634*	*0.2248*	*0.6943*	*5.8624%*	*3.8592%*
Greece	*5.6471*	*0.3833*	*-0.2110*	*30.0244%*	*1.5462%*

Table 1. Parameters and Tail Probability of Models

In order to compare with the result in other area, we refer to the Greek earthquake magnitude data Zimbidis [1] to join our empirical analysis. Table 1 gives the probability of extreme value distribution model for different seismic regions in the earthquake and strong earthquake, if the annual maximum magnitude between 6.0-7.0 of the Richter scale of earthquake is defined as a moderate earthquake, It also compare Greece with Taiwan, China, Yunnan, Xinjiang and Tibet moderate earthquake probability is higher. For the annual maximum magnitude of more than magnitude 7.0 strong earthquake in the provinces of the study in addition to the few provinces of Fujian and Gansu and Shaanxi and other provinces of the probability of occurrence of strong earthquakes are much higher than the Greek, Taiwan and even up to 25%. As a relatively dense population, the economy is relatively developed areas of Beijing, Tianjin and Sichuan earthquake probability were 5.7% and 5.1%, far higher than that of Greece. Earthquake insurance and the corresponding seismic disaster financing mechanisms should be built in these areas.

From the extreme value distribution of earthquake magnitude on the parameters and the tail probability, we can not see the higher seismic risk between the different regions of danger at the lower. For example, the low probability of moderate earthquakes of the Neimeng province, but the earthquake high probability of occurrence of the price of catastrophe bonds, in which case you can use comprehensive measure of the size of the loss caused by the earthquake. We can use a class of the same magnitude triggered catastrophe bonds priced on different areas of earthquake risk. The formation of bond prices as a comprehensive indicator of the size of the regional seismic risk.

Pricing China's earthquake bonds

Firstly, we design a simple earthquake bond, which range in annual maximum earthquake magnitude to determine the different bond payment. We simply follow the trigger bond Zimbidis a magnitude in the Greek earthquake bond pricing[1]. During $[0, T]$, the bonds pay a coupon at the end of each year, the coupon amount depends on a certain place when the maximum earthquake magnitude M, such as $5.8 < M \le 6.2$. The coupon rate is R_l; When the largest magnitude M between 5.4 to 5.8, the coupon rate is $2R_l$, but if $M \le 6.2$, there is no coupon to be paid. The par value K is redeemed when the bond expires in the year T. Throughout $[0, T]$, investors will be paid in full to the maximum magnitude over 6.6. If the maximum magnitude over 7.4 in a year, investors lose all of the expiry of the redemption amount. (See Figure 2)

In a word, bond payment function can be represented by the indicator function as follows:

$$f(R_l, M_l) = \begin{cases} (3R_l)*1_{[0<M_l\le 5.4]} + (2R_l)*1_{[5.4<M_l\le 5.8]} + (R_l)*1_{[5.8<M_l\le 6.2]} \\ for \quad l = 1, 2, \cdots T-1 \\ (3R_l)*1_{[0<M_l\le 5.4]} + (2R_l)*1_{[5.4<M_l\le 5.8]} + (R_l)*1_{[5.8<M_l\le 6.2]} + \\ +K*1_{[5<\max(M_l)\le 6.6]} + \frac{2}{3}K*1_{[6.6<\max(M_l)\le 7.0]} + \frac{1}{3}K*1_{[7.0<\max(M_l)\le 7.4]} \\ for \quad l = T \end{cases} \quad (3)$$

We can refer to Zimbidis [1], it is assumed by the Chinese government launched a national unity, applicable to various regions of the earthquake risk in catastrophe bonds. The deadline for the assumption that the bonds for five years, the value of the nominal value and full redemption is 1000 yuan, the first phase of the coupon rate of 2.25%, the first one, the coupon rate on the basis of the future of the coupon rate follows a geometric Brownian motion. The discount rate follows LN(-3.94, 0.061)[2]. The results are shown in Figure 3, the degree of seismic risk for the comparison of various regions, we add the results obtained by Zimbidis [1].

Because the simulation of the basic assumptions and parameter settings are identical, the bonds price in different areas are comparable to the Greek earthquake catastrophe bonds.

[1]Strictly speaking, the correspondence between the magnitude range and the bonds pay is determined by the bond issuer, from which to consider the insurer's ability to resist risks, but also consider the regional geological structure, the level of economic development and property distribution. It is a complex problem. We ignore the differences in order to reflect the same magnitude earthquake losses.

[2]To understand the Stochastic simulation of floating interest rates. See Zimbidis [1].

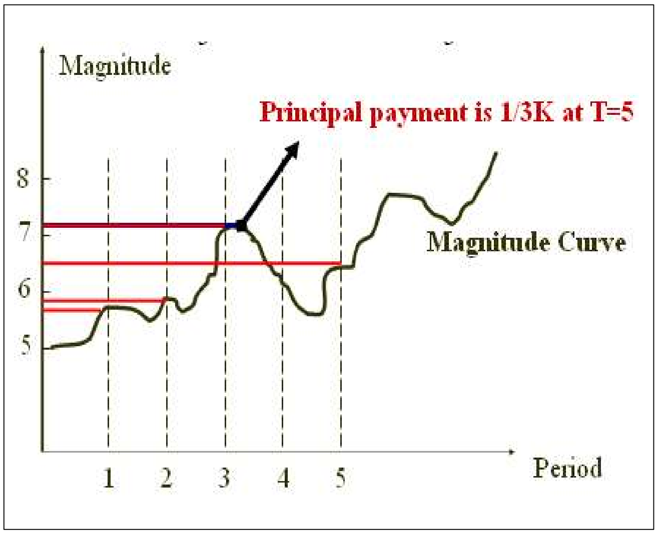

Figure 2. Payment of coupons and par value

(*Par value* = *K*, *T*= 5)

By the earthquake catastrophe bond prices reflect the higher the seismic risk areas, the reasonable price of the bond, the lower to reflect this potential risk or loss. The calculated results show that regional earthquake risk in China is very unbalance, even without considering the different regional economic development and population density differences, the spatial distribution of earthquake risk is also very complicated. Compared to an earthquake-prone European countries, Greece, Taiwan, China, Yunnan, Xinjiang, Tibet and Qinghai, the five regions of seismic risk even higher than that of Greece. Demographic and socio-economic development situation of the five regions, the population of Taiwan and Yunnan region is relatively dense, good economic development. Therefore, on the earthquake in terms of risk exposure to the establishment and promotion of the earthquake insurance and earthquake catastrophe bond financing system more urgent.

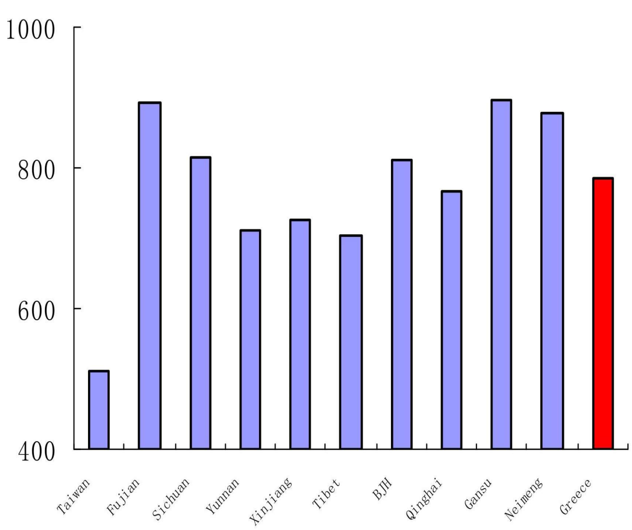

Figure 3. Prices of seismic bonds in regions (par value = $1000)

It is similar seismic risk to face in Sichuan and Beijing-Tianjin-Hebei region ,just as in Greece, As a national economic?. political and cultural center, Beijing has the huge population, as well as Chengdu,which is the financial center in west of China,. Even a moderate earthquake will bring huge losses in these areas. So in Tangshan earthquake, or in Wenchuan, the loss is even hard to assess. In mainland China, this paper considers the various regions of the country to establish the urgency of the earthquake catastrophe risk compensation mechanism is not the same. In Beijing, Tianjin and Sichuan and Yunnan region should be first.

5. Conclusion

In this paper, we employ the Fisher-Tippett-Gnedenko theory, focus on the distribution of annual maximum magnitude in China's major earthquake-prone provinces from 1970 to 2009. Furthermore, we use stochastic simulation method to price the earthquake catastrophe bonds in all earthquake-prone provinces, given the case of a hypothetical five-year capital market. It may be very useful for the insurers and investors from the finance industry and the governmental authorities in China, who realize that the bonds demonstrate an innovative solution. For the catastrophe bond issue varies, priorities should be given to promote the risk financing mechanisms in Beijing-Tianjin-Hebei region Yunnan and Sichuan. Due to the earthquake magnitude and the final earthquake losses, the ultimate loss of the insurance industry is not exactly the same follow-up research is to portray different parts of the earthquake insurance losses as accurately as possible how the earthquake magnitude. As the population density and economic development in the earthquake region in the same scale of earthquake consequences there may be worlds apart. Insurance losses influencing factors reflected in the of the debts design of catastrophe bonds, insurance institutions and research departments to establish a more comprehensive database of earthquake losses. Generally, through the preparation of earthquake insurance loss index (PCS index) to integrate the various types of impact factors reflect the earthquake loss from foreign catastrophe. Therefore, as soon as the preparation of the catastrophe loss index, and the launch of the index as a trigger mechanism of catastrophe bonds, to further improve the efficient and effective way of catastrophe bond financing.

Acknowledgment

The authors wish to thank Dr. Wang Kuangzheng for useful suggestions.

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