Earthquake Catastrophe Bond Pricing

Subjects: Business, Finance

Contributor: Wulan Anggraeni, Sudradjat Supian, Sukono Sukono, Nurfadhlina Binti Abdul Halim

The potential for economic losses due to earthquakes keeps increasing due to the development of the socioeconomic system and urbanization. The disaster management funds are insufficient to cover the losses suffered. Therefore, there is a need for an alternative funding mechanism linked to the financial market, such as catastrophe bonds.

Keywords: earthquake disaster ; bond pricing model ; extreme value theory

1. Introduction

Large-magnitude earthquakes cause extensive damage, loss of life, and economic losses in developing and developed countries [1][2][3][4][5]. Examples include the earthquakes in Colombia (1999, 6.2 Mw, 2000 victims) [6], Haiti (Hispaniola, 2010, 7.0 Mw, 222.570 victims, USD 8 billion in economic losses), Indonesia (Aceh, 2004, 165,708 victims, USD 4.4 billion), Iran (2003, 26,976 victims, USD 0.5 billion), Pakistan (2005, 73,338 victims, USD 5.2 billion) [7], Mexico (Gulf of Tehuantepec, 8.2 Mw, 2017, 98 victims) [8], Peru (45 km west-northwest of Chincha Alta, 2007, 8.0 Mw, 519 victims) [9], China (Wenchuan, 2008, 87,476 victims, USD 85 billion) [7], Chile (2010, 8.8 Mw, 521 victims, USD 30 billion) [10], Tohoku (2012, 9 Mw, 15,000 victims, USD 411 billion), and Nepal (2015, 7.8 Mw, 8000 victims) [11]. The potential for economic losses due to earthquakes keeps increasing due to the development of the socioeconomic system and urbanization [12]. The disaster management funds are insufficient to cover the losses suffered [13]. Therefore, there is a need for an alternative funding mechanism linked to the financial market, such as catastrophe bonds [14].

The countries that have sponsored earthquake bonds and collaborated with the World Bank in their issuance are Mexico, Peru, Chile, Colombia, and the Philippines. **Table 1** presents the data related to the issuance.

Table 1. Earthquake catastrophe bonds issued by the World Bank.

Date of Issues	Sponsor	SPV	Value	Peril	Trigger Type
May 2006	**FONDEN**	**Cat-Mex Ltd.**	**USD 160 million**	**Earthquake in Mexico**	**Parametric**
October 2009	**FONDEN**	**Multicat Mexico Ltd.**	**USD 290 million**	**Tornado and earthquake in Mexico**	**Parametric**
August 2017	**FONDEN**	**IBRBD CAR 113–115**	**The US $360 Million**	**Tornado and earthquake in Mexico**	**Parametric**
February 2018	**Republic of Chile**	**IBRD CAR 116**	**USD 500 million**	**Earthquake in Chile**	**Parametric**
February 2018	**Republic of Colombia**	**IBRD CAR 117**	**USD 400 million**	**Earthquake in Colombia**	**Parametric**
February 2018	**FONDEN**	**IRBD CAR 118–119**	**USD 260 million**	**Earthquake in Mexico**	**Parametric**
February 2018	**Republic of Peru**	**IBRD CAR 120**	**USD 200 million**	**Earthquake in Peru**	**Parametric**
November 2019	**Republic of the Philippines**	**World Bank IBRD 123–124**	**USD 225 million**	**Earthquake and tropical cyclone in the Philippines**	**Modeled loss**

Source: www.artemis.bm, accessed on 5 May 2022, note: SPV (Special Purpose Vehicle).

The data in **Table 1** show that the World Bank's earthquake catastrophe bonds range from USD 160 million to USD 500 million. On 8 September 2017, Mexico was rocked by an earthquake of magnitude 8 Mw, causing investors to lose all cash and coupon values. Similarly, the 2018 earthquake in Peru, with a magnitude of 8 Mw, caused investors to lose 30% of their cash value. Based on this real case, earthquake bonds aid the sponsoring countries in procuring disaster funds. However, they pose a moral hazard to investors [13][14][15] due to disaster losses that must be borne by sponsors approaching the trigger specified in eliminating the law pliers. When this happens, no investors will be drawn to purchase the bonds. Therefore, an accurate and transparent earthquake catastrophe bond pricing model is required in order to succeed in the market [16].

In earthquake bond pricing, the catastrophe risk needs to be modeled first. Extreme events related to historical observations can be described using EVT. In particular, the theory of extreme values in catastrophe bonds (CAT bonds) is used to study the distribution of extreme values related to the trigger parameters used in the model (e.g., loss, mortality, flood height, earthquake magnitude, etc.).

The systematic reviews of CAT bonds that have been carried out previously are briefly described in this paragraph. Pizzutilo and Venezia [17] analyzed the effectiveness of catastrophe bonds for the transportation and infrastructure industries; the results showed that catastrophe bonds benefit from managing potential losses related to disaster events. Calvet et al. [18] reviewed statistical and machine learning methods in designing trigger mechanisms; the results indicated that statistical methods and machine learning provide great gains in accuracy and efficiency by decreasing the classification time. Wu and Zhou [19] reviewed the catastrophe bond instrument and the modeling approach used; the research found that the three most popular models used in modeling disaster losses are the compound Poisson model, jump diffusion, and double-exponential jump diffusion. Sukono et al. [20] also reviewed the use of the compound Poisson process; the results were obtained for 30 selected articles, with 12 articles using constant interest rates, while 18 did not; furthermore, 8 articles used CIR, 5 articles used Vasicek, 2 used the robust approach, 1 article used CIR and Vasicek, 1 used the Hull–White model, and 1 article used the ARIMA method.

2. Large-Magnitude Earthquakes

Hurricane Andrew sent 11 insurance firms into bankruptcy because they lacked sufficient reserves to meet claims. As a result, catastrophe bonds were developed in the middle of 1990 [21]. The Chicago Board of Trade launched the first contract in 1992 and introduced a trigger put-and-call option for catastrophes. This option was based on the Catastrophe Loss Index compiled by the Property Claims Service (PCS) and the industry's statistics agency [22]. Over time, CAT bonds are used by reinsurance companies and countries with a high potential for losses due to disasters to obtain alternative funding for disaster management.

Earthquake catastrophe bond pricing models (ECBPMs) require a detailed study of extreme losses, and the disaster severity is analyzed using EVT [23][24]. The extreme value theory of catastrophe bonds was used by Riza et al. [25] to model the distribution of actual losses and fatalities. Using multiple triggers, the research designed a price model for determining disaster bonds with and without coupons. ARIMA was used to model interest and coupon rates, while Burr, GEV, Weibull, GPD, and logistical models were employed to model the distribution of losses and deaths. Furthermore, maximum likelihood estimation (MLE) was used to estimate the parameters, while the nonhomogeneous Poisson process (NHPP) was used to determine the aggregate loss and death. The Nuel recursive method was used to calculate the CDF value of the NHPP. The simulation used data on storm catastrophe losses and fatalities in the United States from 2012 to 2021, the number of storms that occurred in the United States from 1986 to 2021, and USD LIBOR data from 1986 to 2021. The results of the analysis showed that the intensity of the disaster and factors such as the threshold value of losses and deaths affect the price of catastrophe bonds. More intense disasters and longer bond periods reduce the bond price. Additionally, a greater threshold value of the two triggers increases the bond price.

Marvi et al. [26] modeled multi-period bond pricing for multi-hazard and multiregional disasters. The study used GEV type II or Frechet methods to model the distribution of water levels and employed a binary function to model cash value. The Monte Carlo simulation method was used to generate water level data, and a hydraulic flow model was used to determine the flood depth and flood intensity in buildings in an area. The multi-hazard and multiregional models could reduce the residual risk and benefit the insurance companies.

Chao [27] developed a methodology to account for various risks while pricing multi-period catastrophe bonds. The Poisson process was used to model the number of disaster events up to time t, while the CIR and GPD were used to model interest rates and the distribution of loss variables, respectively. Furthermore, the MLE was used to estimate the parameters, while the copula was used to model the dependence distribution of economic losses and deaths. The Kolmogorov–Smirnov test was used to assess the viability of choosing the copula model, and the sensitivity analysis was used to evaluate the impact of interest rates and GPD parameters on the bonds. The findings showed that the interest and the average long-term interest rates have an inverse relationship with catastrophe bond prices. However, there was a strong correlation between economic losses and mortality raising the price of disaster bonds.

Deng et al. [28] modeled multi-period drought bond prices. POT was used to determine the loss threshold, while GPD was employed to model the distribution of losses. Moreover, the study used a binary function to model the face value of bonds and a Poisson process to determine the number of disasters at time t. The Lagrange method, also known as MLE, was used to estimate the GPD distribution parameters. The results showed that a higher probability of a disaster-triggering event reduces catastrophe bond prices. High-risk investments provide a high-yield stimulus and attract many investors.

Chao and Zhou [29] modeled multi-period catastrophe bond pricing. The study used the Poisson process to determine the number of disaster bonds at time *t* and the CIR to model the interest rate. POT was used to obtain extreme values of deaths and economic losses due to disasters. Moreover, the copula was used to model the dependency distribution of deaths and economic losses, while Monte Carlo simulations were utilized for the experiments. The sensitivity analysis determined the impact of disaster intensity, maturity time, and the magnitude of the tau–Kendall correlation on catastrophe bond prices. The results showed that a catastrophe bond pricing model triggered by many events has a lower risk than a model with a single triggering event. It also has a larger market potential than ordinary bonds and has low risk and high returns, reducing the moral hazard. Catastrophe bond prices have an inverse relationship with disaster intensity, maturity time, and the value of the tau–Kendall correlation. The disaster intensity's effect on the maturity time is greater than that on the price.

The previously developed model was applied to storms [25], floods, and drought [28], and is generally not specific to drought, earthquakes, or floods [29]. The trigger types used were modeled loss [25][27][28], industry loss [29], and parametric [26]. The parametric trigger type has high transparency and baseline risk, short settlement time, and low regulatory acceptance, while the opposite is true for the indemnity type [30]. This shows that the parametric type is better than other triggers for investors but poses a basic risk to the sponsor. In comparison, the GEV distribution could eliminate other extreme data in a period [27]. Investors also face financial risk, implying fluctuating interest rates, inflation, and coupons that affect the cash value of bonds. The model's methods are ARIMA [25] and CIR [15][21]. However, ARIMA allows negative values. CIR also assumes constant volatility, which is unrealistic.

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