

Research Article

Research on the Pricing of Global Drought Catastrophe Bonds

Guoqu Deng ¹, Shiqiang Liu,¹ Li Li,¹ and Chushi Deng²

¹School of Management, Henan University of Science and Technology, Luoyang 471003, China

²Business School, Deakin University, Melbourne, Victoria 3125, Australia

Correspondence should be addressed to Guoqu Deng; dengguoqu@haust.edu.cn

Received 29 February 2020; Accepted 7 April 2020; Published 23 May 2020

Guest Editor: Wenguang Yu

Copyright © 2020 Guoqu Deng et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The rapid development of catastrophe bonds provides a new idea for catastrophe risk dispersion, since its traditional means fail to afford the economic losses caused by the global drought catastrophe. With the deepening of the concept of the community with a shared future for mankind, there is an opportunity to issue global drought catastrophe bonds through international cooperation. Based on the data of global drought catastrophe losses from 1900 to 2018, this paper selects 21 countries as the primary participants of international cooperation and studies the pricing of drought catastrophe bonds by the POT model and high quantile estimation. The results show that the first-class bond has a 10% occurrence probability with the trigger point of \$252.54 million, and the second-class one has a 35% occurrence probability with the trigger point being \$117.13 million. In line with high quartile estimates, the one-year principal-protected catastrophe bonds with a face value of \$1,000 are valued at \$957.14 and \$939.29, respectively. Besides, the principal portion of the lost bonds is \$912.50 and \$783.04, while the total of it is \$867.86 and \$626.79, respectively.

1. Introduction

According to a report by the CRED (Center for Research on Environmental Decisions), 347 droughts were recorded between 1998 and 2017, resulting in economic losses of about \$124 billion; droughts affected the lives of around 1.5 billion people worldwide, accounting for 33 percent of the people affected by all disasters. At the same time, China is one of the most severely affected countries in the world. In 2017 alone, the drought caused a direct economic loss of 37.5 billion yuan, which is 12.4% of China's annual economic losses. It is very serious to issue catastrophe financial derivatives, such as catastrophe insurance and the catastrophe bond, owing to the limited affordability of the traditional insurance industry, as well as undersupply in government relief and social contribution.

Recent years witness a relatively significant increase in both the global issuance of catastrophe bonds and the annual aggregate trading volume. Even under the circumstances of the 2008 financial crisis, the issuance of global catastrophe bonds has also been comparatively unscathed. With the vital

function of dispersing catastrophe risk, catastrophe financial derivatives such as catastrophe bonds have been integrated into the mainstream financial market, turning into an effective tool for catastrophe risk management and capital market investment. In January 2011, Swiss Re reached an agreement with Successor X Ltd. ("Successor X") by integrating earthquake risks in Australia with those in the United States. Besides, catastrophe risks in Australia, North Atlantic hurricanes and California earthquakes have been comprehensively covered, which has set an example of cooperation among different countries with various disasters. With the wide acceptance of the community of human destiny, the cooperation among countries in related fields is deepening, and international cooperation in the field of catastrophe is bound to become a part of it.

Through the collation of relevant literature, the related research of catastrophe bonds mainly focuses on three aspects: The first is the catastrophe bond pricing model. In terms of catastrophe bonds, Papaioannou and Pantelous [1] deduced the pricing formula by the Markov process, and Nowak and Romaniuk [2] proved the valuation formula with the generalized structure suitable for different yield

functions by using the multifactor CIR model. He et al. [3] used the flood loss data in China to fit the model. Compared with other models, the POT model has better fitting effect and precision based on the results. To establish the pricing model, the catastrophe bond and convertible bond are combined into the catastrophe convertible bond by Wang [4]. The second is the influence of related factors on the price of the catastrophe bond. Lee and Yu [5] proved that moral hazard and basis risk can remarkably reduce the price of catastrophe bonds by introducing them into the ISR model. Kang and Xing [6] analyzed that efficacious asset-liability management can lower the impact of morals, default, and the basis on the catastrophe bond price, while Ma et al. [7] simulated the impact of interest rate risk on the catastrophe bond price. The third is the application research of the catastrophe bond. Shao et al. [8] priced California earthquake catastrophe bonds in line with neural network financial structure and equilibrium pricing theory. For the pricing of agricultural charity catastrophe bonds, Deng et al. [9] used the modified Wang two-factor model. Based on extreme value theory, Wu et al. [10] adopted the POT model to design typhoon catastrophe bonds. The latest application research has focused on Fourier transform by Yu et al. [11–13] and Zhang et al. [14].

According to the existing research results, there are theoretical research and application research for catastrophe bonds. The former mainly focuses on various pricing models and factors affecting pricing; the latter involves practical application pricing of flood, earthquake, and typhoon catastrophe bonds. However, no intersection about the catastrophe bond and the drought catastrophe risk has been discovered in the literature. Based on the abovementioned analysis, this paper applies the POT pricing model and attempts to price the drought catastrophe bonds using the global drought catastrophe loss data. This is the first time that catastrophe bond pricing has been applied to drought and catastrophe, with the research horizon based on global losses. Through the study on the pricing of drought catastrophe bonds, we hope to provide a new idea and means for the global drought catastrophe risk dispersion.

2. Definition of Catastrophic Drought Disaster and Loss in the World

At present, there lacks a special consistent standard of drought catastrophe at home and abroad. Zhang et al. [15] put forward five conditions: the direct economic loss of a single disaster exceeds 100 billion yuan; the proportion of disaster-causing crops exceeds 60%; the area of disaster-affected crops exceeds 50000 km², the disaster-affected population exceeds 50 million, and the population in need of relief exceeds 30%. When any three of the five conditions are met, the situation can be considered as having reached the level of drought catastrophe. For Swiss Re [16], a single loss of more than \$97.6 million is called a catastrophe. Deng et al. [17] defined the criteria for catastrophic disasters from different subjects. For disaster-bearing farmers, agricultural insurance brokers and the government, we can call it an agricultural catastrophe when the cumulative losses from a

disaster exceed 40,800 yuan, 141.51 million yuan and 1% of the GDP of the year, respectively. As the second-largest reinsurance company in the world, Swiss Re has the classification standard generally accepted by the industry. That is to say, if the direct economic losses resulted from a single drought reach up to \$97.6 million, we can perceive it as a drought catastrophe.

From 1900 to 2018, there were 633 severe droughts in the world, resulting in more than \$167 billion in economic losses. In terms of regional distribution, Asia with 149 disasters suffered the most, bringing out economic losses of \$56.54 billion; North America ranked the second because of \$48.91 billion losses in the economy, with a single and largest average loss of \$740 million; Europe ranks the third with less frequent economic losses of \$26.6 billion. For Oceania, there were 19 times of disasters that generate a total economic loss of \$12.79 billion; for Africa, and it had 282 times of droughts and catastrophes, which is the highest number that far exceeds other regions, but economic losses amounted to only \$5.24 billion; the Caribbean region had the lowest disaster losses, with 17 disasters costing merely \$350 million (Figure 1).

The number of drought catastrophes and economic losses in various countries around the world are calculated, with the top 10 countries shown in Table 1. China had the highest number of droughts, namely, 39, far beyond that in other countries and twice as many as that in Brazil. In terms of economic losses, the United States ranked the first with a combined loss of \$41635 million, followed by China and Brazil (Table 1).

3. Pricing Model of Drought Catastrophe Bonds

The classical pricing models of catastrophe bonds include the Kreps model, the POT model, and the Wang transformation model. As the first model is mainly applied to actuarial insurance, it fails to reflect the tail characteristics of catastrophe risk effectively. While the Wang transformation model assumes that the risk probability model is known, the POT model based on extreme value theory is more propitious to the pricing when the probability of drought and catastrophe risk is unknown. In regard of pricing catastrophe bonds, the threshold, term structure of the interest rate, and the catastrophe loss model are the key factors.

3.1. Threshold Value. The threshold value (marked as U) is the key to the determination of bond prices. To determine the threshold value, domestic scholars normally use the graph of the average out-of-quantity function, which is a relative range instead of an exact value. With the simple and explicit process, the Kurtosis method proposed by Piere Patie is more significant to determine the threshold of the loss probability distribution model. After repeated elimination of the data, the Kurtosis of the new sample data is less than 3, and then the maximum value of the new sample data can be used as the threshold value. The Kurtosis is calculated as follows:

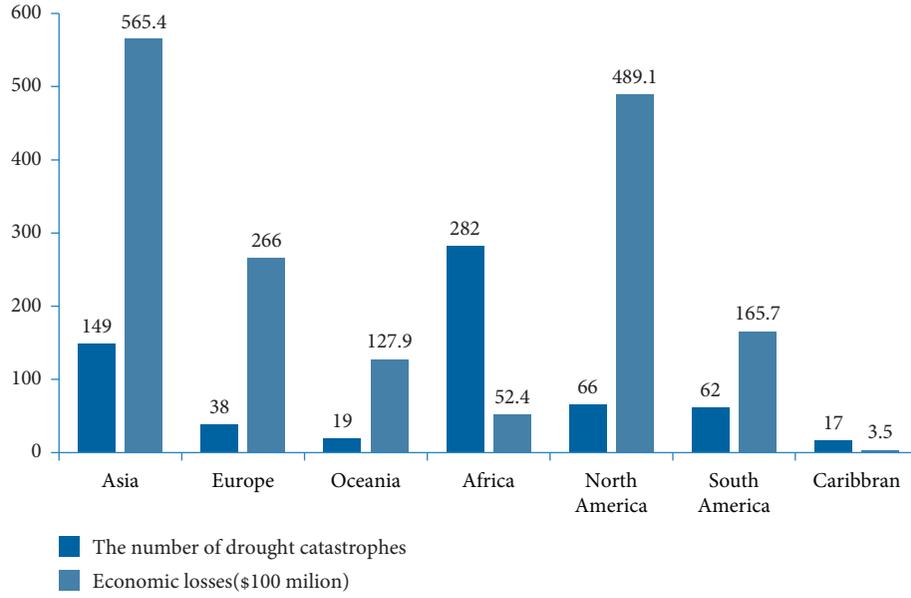


FIGURE 1: The number of drought catastrophes and economic losses in the world from 1900 to 2018.

TABLE 1: Top 10 countries for frequency of drought catastrophes and economic losses from 1900 to 2018.

Rank	Number of disasters countries		Economic losses (million)		
	Number	Countries	Rank	Countries	Losses
1	39	China	1	United States	41635
2	18	Brazil	2	China	35346.4
3	16	Ethiopia	3	Brazil	10183.1
4	15	United States	4	Spain	9660
5	15	India	5	Vietnam	7399.1
6	15	Kenya	6	India	5441.1
7	15	Somalia	7	Canada	4810
8	15	Niger	8	Italy	4290
9	14	Mauritania	9	Thailand	3725.5
10	13	Mozambique, Burkina Faso, Bolivia	10	Argentina	3520

$$K_n = \frac{(1/n) \sum_{i=1}^n (X_i - \bar{X})^4}{(S_n^2)^2}, \quad (2) \quad (1)$$

3.2. *Term Structure of Interest Rates.* Generally, the maturity of catastrophe bonds is short term (three years, even one year). As the interest rate will not vary much during the bond cycle, we use a relatively simple static term structure of interest rates in this paper.

3.3. *Catastrophe Loss Model.* The coupon-free catastrophe bond with a face value of 1 is payable when it matures in the following structure:

$$P_{\text{cat}}(T) = \begin{cases} 1, & L_T < U, \\ p, & L_T > U. \end{cases} \quad (3)$$

Among them, L_T is the total amount of loss in the bond term, with the bond term between each loss being

independent and identically distributed; U denotes the threshold; and p represents the proportion paid by investors when the trigger level is reached.

Assuming that the number of catastrophes at time t obeys Poisson distribution of strength, X_i signifies that the losses at time X_i are independent and follow GPD distribution. Then, L_i , the total loss of the catastrophe, obeys Poisson distribution and can be expressed as follows:

$$L_i = X_1 + X_2 + \dots + X_{N_i} = \sum_{i=1}^{N_i} X_i. \quad (4)$$

The probability that the catastrophe loss is less than the threshold U is

$$P(L_t < U) = \sum_{j=0}^{\infty} e^{-\lambda T} \frac{(\lambda T)^j}{j!} F^j(U). \quad (5)$$

Among them, $F^j(U) = P(X_1 + X_2 + \dots + X_j \leq U)$ is the j convolution of catastrophe loss.

4. Price Calculation of the Drought Catastrophe Bonds

4.1. Data Source. The following data are obtained from the EM-DAT (<https://www.emdat.be/>) and the database (1900–2018). Based on the Swiss Re catastrophe, the criteria is \$97.6 million for a single loss; based on Disaster Management Index INFORM¹, the drought risk rating should be medium or higher. Countries having a land area of more than 300,000 square kilometers or meeting the above-mentioned conditions will be the subjects of international cooperation. The final group of 21 countries will be Vietnam, Zimbabwe, Bolivia, China, Thailand, India, Brazil, Philippines, Italy, Mexico, Ethiopia, Spain, Russia, Mauritania, Peru, Canada, Namibia, Argentina, South Africa, the United States, and Australia. A total of 82 drought events reached the catastrophic level, with effective years from 1968 to 2018. Due to the large time span, the CPI in 2018 is deemed as the benchmark 100 to adjust the losses of all previous drought catastrophes.

4.2. Descriptive Statistics. First of all, the data obtained are descriptive statistics. In the period of 1968–2018, there were 36 years of drought catastrophes and 15 years of a catastrophe. As the most frequently affected year, 2015 witnessed 9 times of catastrophic events, and the cumulative loss was \$18.04 billion. In 2012, the cumulative economic loss was the largest on record at \$21.75 billion.

Poisson distribution is suitable for the number of random events in decimal unit time. Many scholars used Poisson distribution to predict the number of natural disasters, such as Liu [18] and Xie Zhuolun [19]. Supposing that the frequency of drought disasters obeys Poisson distribution in this paper, Poisson intensity can be calculated from the frequency statistics λ :

$$\lambda = \frac{\sum N_i * x_i}{\sum x_i}, \quad (6)$$

where N_i represents the number of drought and x_i denotes frequency of occurrences. According to Table 2, the calculation result is $\lambda \approx 2.28$.

As can be seen from Table 3, the average loss from a single drought catastrophe was \$145 million, with a maximum value of \$1828.66 million. The whole sample data skewness is 4.63, which has the obvious right-skewness characteristic. Nevertheless, the Kurtosis is more than 3, with the apparent peak feature. From the sample data normal probability chart (Figure 2), the sample data are the right-skewness peak thick tail data, thus conforming to the traits of catastrophe risk distribution.

The frequency histogram and the empirical loss function of the catastrophic loss concerning drought disaster are plotted, based on which Figures 3 and 4 are obtained. According to the comprehensive statistical description analysis table and the normal probability graph of sample data, the sample data is right-biased thick-tailed data, which can meet the data characteristics of extreme value theory analysis and catastrophe data.

4.3. Loss Distribution Function of Drought Catastrophe. Since the threshold value calculated by the Kurtosis method is 115.3512, we selected 117.13, which is the nearest from 115.3512, as the threshold value. Finally, 52 data are eliminated from the sample data, and there are 30 data exceeding the threshold value, which are used as the tail parameter estimation data of the GPD distribution.

When we fit the GPD distribution data, the oversize distribution function is constructed as follows:

$$F_u = P(X < u + y | X > u), \quad X \geq 0, \quad (7)$$

where u is the threshold and $y = x - u$ represents excess value. After transformation, we obtain

$$F_u(y) = \frac{F(y+u) - F(u)}{1 - F(u)} = \frac{F(x) - F(u)}{1 - F(u)}. \quad (8)$$

According to the Pickands-Balkema-Haan theorem, when the threshold is large enough, there exists a nondegenerate distribution function $H_{\xi, \sigma}$ for a class of conditional overdistributions of F_u :

$$F_u(y) = H_{\xi, \sigma}(y), \quad u \rightarrow \infty, \quad (9)$$

$$H_{\xi, \sigma}(y) = \begin{cases} 1 - \left(1 + \frac{\xi}{\sigma} y\right)^{-1/\xi}, & \xi \neq 0, \\ 1 - e^{-y/\sigma}, & \xi = 0. \end{cases} \quad (10)$$

In this case, $H_{\xi, \sigma}$ represents the generalized Pareto Distribution; ξ denotes the shape parameter; and σ represents the scale parameter.

If $y = x - u$ is transformed to $x = y + u$, the GPD function can be expressed as follows:

$$H_{\xi, \sigma}(x) = \begin{cases} 1 - \left(1 + \frac{\xi}{\sigma}(x - u)\right)^{-1/\xi}, & \xi \neq 0, \\ 1 - e^{-(x-u)/\sigma}, & \xi = 0. \end{cases} \quad (11)$$

If N_u represents the number that loss exceeds u , namely $x > u$, we can obtain

$$F_u(x) = H_{\xi, \sigma}(x) = \begin{cases} 1 - \frac{N_u}{N} \left(1 + \frac{\xi}{\sigma}(x - u)\right)^{-1/\xi}, & \xi \neq 0, \\ 1 - \frac{N_u}{N} e^{-(x-u)/\sigma}, & \xi = 0. \end{cases} \quad (12)$$

When the Lagrangian is applied to the maximum likelihood function of the GPD function, the shape and scale parameters can be derived to estimate the parameters of the GPD $\xi = 0.519$, $\sigma = 73.619$, and the position parameters $\theta = (\sigma/\xi) = 141.848$. At that time, the maximum likelihood of the extremum is regular, and the asymptotic properties (consistency, asymptotic effectiveness, and asymptotic normality) of the criteria are satisfied, and thus the parameters can be estimated by the use of the standard asymptotic likelihood conclusion.

TABLE 2: The annual number of drought catastrophic statistics from 1968 to 2018.

Number of droughts	1	2	3	4	5	6	9
Frequency of occurrence (in years)	15	9	6	4	0	1	1

TABLE 3: Descriptive statistics of drought catastrophes losses from 1968 to 2018.

Min	Max	Mean	Standard deviation	Extreme bad	Degree of deviation	Kurtosis
9.8	1828.66	145	241.26	1825.36	4.63	30.34

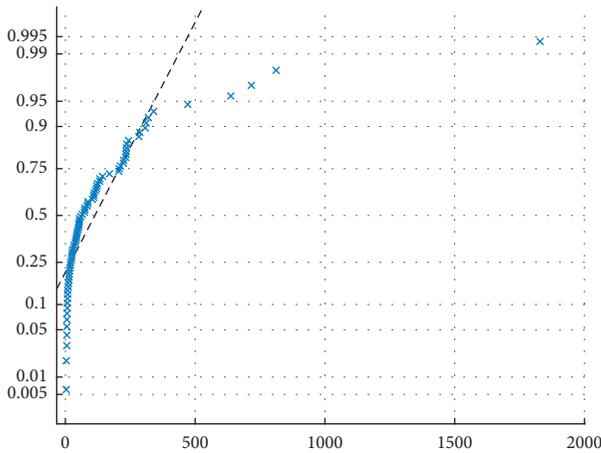


FIGURE 2: Normal probability chart of sample data.

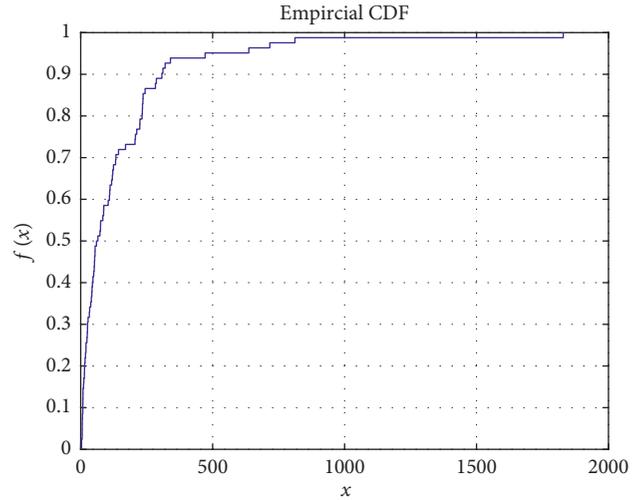


FIGURE 4: Empirical distribution function diagram of drought catastrophe loss.

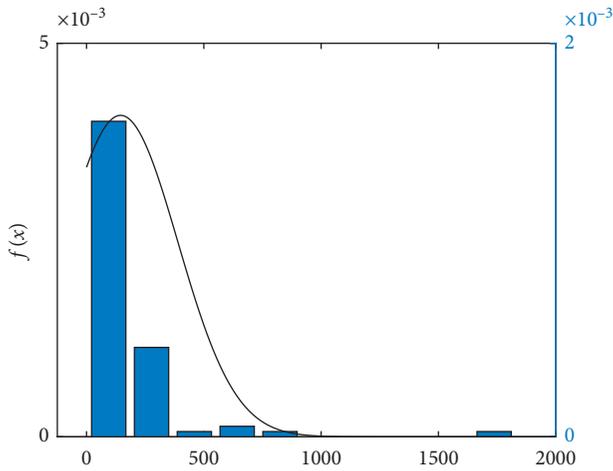


FIGURE 3: Histogram frequency of drought catastrophe loss.

Once the relevant parameters have been determined, a generalized Pareto distribution function can be acquired:

$$H_{\xi,\sigma}(x) = 1 - \left(1 + \frac{0.519}{73.619}(x - 117.13)\right)^{-1/0.519}, \quad x > 117.13. \tag{13}$$

The distribution function of the losses regarding drought catastrophic disasters is

$$F(x) = 1 - \frac{30}{82} \left(1 + \frac{0.519}{73.619}(x - 117.13)\right)^{-1/0.519}, \quad x > 117.13. \tag{14}$$

4.4. High Quantile and Price Estimation. Formula (9) can be used for the estimation of the high quantile of the loss resulted from drought catastrophic disaster. If the value of the quantile is p , the formula for estimating the high quantile is as follows:

$$x_p = u + \frac{\sigma}{\xi} \left(\left(\frac{n}{N_u} (1 - p) \right)^{-\xi} - 1 \right). \tag{15}$$

From the above, we can obtain $u = 117.13$, $\sigma = 73.169$, $\xi = 0.519$, $n = 82$, and $N_u = 30$. The given values of p are 90%, 95%, 99%, and 99.5%, respectively. Moreover, the high scores of drought catastrophic losses are calculated, as shown in Table 4.

From the results, the likelihood that the global drought catastrophe loss will be less than \$252.54 million will be 90%. When global drought catastrophe loss is less than \$372.20 million and \$889.24 million, the probability will be 95% and 99%, respectively. Besides, the probability when the loss reaches up to \$1,284.58 million or less is 99.5%. In terms of national losses, the United States and China each suffered

TABLE 4: High percentile statistical table of drought catastrophe losses.

U	N_u	σ	ξ	90%	95%	99%	99.5%
117.13	30	73.169	0.519	252.54	372.2	889.24	1284.58

three single losses of more than \$252.54 million, while Brazil, Argentina, Vietnam, Thailand, and India each suffered one drought calamity of over \$252.54 million.

When the drought catastrophic losses were \$117.13 million, the quantile was 65 percent. To enhance the appeal of drought catastrophe bond design, the bond price is designed in accordance with different loss levels. In this regard, the trigger value of the first bond is designed as (252.54, 10%), and that of the secondary bond is (117.13, 35%). Suppose the bond has a face value of \$1,000, a coupon of 8 percent, a risk-free interest rate of 12 percent, and a maturity of one year:

- (1) The price of the drought catastrophe bond of the principal-protected type: if the drought catastrophe does not occur or does not meet the set trigger conditions, the investor may recover the principal and interest at the end of the period; otherwise, the SPV will no longer pay interest to the investor, who will only get their money back.

The issue price of the first bond is $P = (1080 * 90\% + 1000 * 10\% / 1 + 12\%) = 957.14$.

The issue price of the secondary bond is $P = (1080 * 65\% + 1000 * 35\% / 1 + 12\%) = 939.29$.

- (2) The price of the drought catastrophe bond of the principal partial loss type: during the payment period, the SPV will charge the investor interest and part of the principal, with the loss rate of the principal being 50%:

The issue price of the first bond is $P = (1080 * 90\% +$

$1000 * 10\% * (1 - 50\%) / 1 + 12\%) = 912.5$.

The issue price of the secondary bond is $P = (1080 * 65\% + 1000 * 35\% *$

$(1 - 50\%) / 1 + 12\%) = 783.04$.

- (3) The price of the drought catastrophe bond with the total loss of principal type: during the payment period, if the drought event reaches the trigger condition, the investor loses all the principal and interest; otherwise, the SPV will pay the investor all the principal and interest.

The issue price of the first bond is $P = (1080 * 90\% + 1000 * 10\% *$

$(1 - 100\%) / 1 + 12\%) = 867.86$.

The issue price of the secondary bond is $P = (1080 * 65\% + 1000 * 35\% *$

$(1 - 100\%) / 1 + 12\%) = 626.79$.

According to the analysis of the data, the loss of drought catastrophic disaster has the right-off peak and tail. Besides, the distribution function of loss obeys the generalized

Vilfredo Pareto's GPD function, which means issuing one-year drought catastrophe bonds with fixed interest rate term structure. Based on the high quartile estimation, the issuing price of the drought catastrophe bonds with a face value of \$1000 is as follows: (1) for the principal principal-protected type, the price of the first- and second-order drought catastrophe bonds is \$957.14 and \$939.29, respectively; (2) for partial loss of principal type with a loss rate of 50%, the price is \$912.50 for first-degree drought catastrophe bonds and \$783.04 for second-degree ones; (3) for total loss of principal type, the price are \$867.86 and \$626.79 for first- and second-degree drought catastrophe bonds, respectively. The yield level of the bond is significantly higher than that of treasury bonds in the same period, which largely appeals to investors.

5. Conclusion

In this paper, dissimilar trigger points and various principal loss are designed, which can provide various options for investors with different preferences. Results show that the issuance price of low-loss and high-probability types of bonds is low. The higher risk means higher return. The high yield stimulus will attract a mass of investors to buy investments. Since the drought catastrophe bond is designed for the first time, the term structure of the fixed interest rate is used for the study to simplify the calculation. Nonetheless, in the actual market operation, the bond price interest rate is in dynamic change. Therefore, we can combine our future research with the actual situation more closely, using the dynamic term structure of the interest rate to price the drought catastrophe bond.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was sponsored by the Key Program of National Social Science Foundation of China (No. 15AGL013), Major policy theoretical and practical issues of China Earthquake Bureau (CEAZY2019JZ09), Risk management innovation and public policy soft science research base of Henan Provincial Science and Technology Department, and Social Science Planning Project of Henan Province (2019BJJ030).

References

- [1] A. D. Papaioannou and A. A. Pantelous, "Pricing and simulating catastrophe risk bonds in a markov-dependent environment," *Applied Mathematics and Computation*, vol. 309, pp. 68–84, Elsevier, Amsterdam, Netherlands, 2017.
- [2] P. Nowak and M. Romaniuk, "Valuing catastrophe bonds involving correlation and CIR interest rate model," *Computational and Applied Mathematics*, vol. 37, no. 1, pp. 365–394, 2018.

- [3] S. He, D. Wu, and S. Wang, "Study on flood disaster loss model based on extreme value theory," *Journal of Yunnan Nationalities University*, vol. 23, no. 1, pp. 62–65, 2014.
- [4] Li Wang, "Research on the pricing model of the convertible bond," *Insurance Journal Research*, vol. 6, pp. 58–67, 2018.
- [5] J.-P. Lee and M.-T. Yu, "Valuation of catastrophe reinsurance with catastrophe bonds," *Insurance: Mathematics and Economics*, vol. 41, no. 2, pp. 264–278, 2007.
- [6] H. Kang and T. Xing, "Research on catastrophe bond pricing in China considering multi-risk factors," *Insurance Journal Research*, vol. 8, pp. 96–108, 2013.
- [7] Z. Ma, X. Zou, and C. Ma, "Pricing and numerical simulation of catastrophe bonds under double stochastic compound poisson loss," *China Management Science*, vol. 24, no. 10, pp. 35–43, 2016.
- [8] J. Shao, A. Pantelous, and A. D. Papaioannou, "Catastrophe risk bonds with applications to earthquakes," *European Actuarial Journal*, vol. 5, no. 1, pp. 113–138, 2015.
- [9] G. Deng, W. Yan, and X. Zhu, "A study on the pricing of agricultural catastrophe bonds in China: a case study of Henan province flood catastrophe bonds," *Financial Theory and Practice*, vol. 5, pp. 91–94, 2016.
- [10] Y. Wu, S. Jiang, and X. Wu, "Study on loss distribution and financial countermeasures of typhoon disaster in Guangdong province based on extreme value theory," *Seismology*, vol. 32, p. 131, 2017.
- [11] W. Yu, Y. Yong, G. Guan, W. Y. Huang, S. Su, and C. Cui, "Valuing guaranteed minimum death benefits by cosine series expansion," *Mathematics*, vol. 7, no. 9, p. 835, 2019.
- [12] W. Yu, F. Wang, Y. Huang, and H. Liu, "Social optimal mean field control problem for population growth model," *Asian Journal of Control*, pp. 1–8, 2019.
- [13] W. Yu, P. Guo, Q. Wang et al., "On a periodic capital injection and barrier dividend strategy in the compound poisson risk model," *Mathematics*, vol. 8, no. 4, p. 511, 2020.
- [14] Z. Zhang, W. Y. Yong, and W. Yu, "Valuing equity-linked death benefits in general exponential lévy models," *Journal of Computational and Applied Mathematics*, vol. 365, 2020.
- [15] W. Zhang, P. Shi, and H. Zhou, "A study on the definition and classification of catastrophe—an analysis of typical disaster cases in the world in recent years," *Disaster Science*, vol. 1, pp. 17–24, 2013.
- [16] Swiss Reinsurance Economic Research, "Natural and man-made disasters in 2014: convective storms and winter storms cause the most damage," *Swiss Re Sigma*, vol. 2, p. 46, 2015.
- [17] G. Deng, H. Han, S. Kang, and J. Liu, *Exploring the Mechanism of Agricultural Catastrophe Risk, Risk Dispersion and Symbiosis in China*, China Social Sciences Press, Beijing, China, 2015.
- [18] J. Liu and Y. Li, "Study on earthquake loss distribution and catastrophe bond pricing in China," *Financial and Trade Studies*, vol. 6, pp. 82–88, 2009.
- [19] Z. Xie, J. Chen, and Ye Lu, "Distribution fitting of earthquake catastrophe risk and bond, pricing in mainland China," *Journal of Zhejiang Sci-Tech University*, vol. 42, no. 1, pp. 10–19, 2019.