

# Pricing Model Construction and Empirical Research on Catastrophe Bond Pricing for Three Major Crops in China

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**Abstract.** Agricultural disaster risks are significant for the sector's development, and existing risk management tools have limitations. This paper introduces a nationwide catastrophe bond for wheat, maize, and rice, offering broad coverage for China's agriculture. The paper utilizes marginal distribution and Copula function fitting to model the disaster losses of the three major crops from 1990 to 2022. It employs Monte Carlo simulation to generate a 10,000-year event set and rank correlation to align simulated data with real data. The bond price is then calculated using the Wang model, addressing the challenge of data scarcity and providing an innovative approach to catastrophe bond design. The study finds that bond prices increase with the coverage period and risk level, with interest-risk bonds offering higher returns and risks than principal-and-interest risk bonds. Catastrophe bonds present a more stable risk diversification method compared to reinsurance, both in terms of returns and potential losses. To further the development of agricultural catastrophe bonds, the paper recommends optimizing the issuance environment and establishing a robust market infrastructure.

**Keywords:** agricultural catastrophe bonds; Copula function; Wang two-factor model.

## 1. Introduction

Agriculture, being the cornerstone of the national economy, plays a critical role in economic and social stability. However, it is highly susceptible to natural conditions, and climate change has led to frequent extreme weather events, challenging agricultural production. Disaster risks like droughts, floods, and pests can reduce crop yields and quality, impacting farmers' livelihoods. Recognizing and managing these risks is essential for the sustainable development of agriculture and the economy.

The agricultural insurance market is currently inadequate in covering modern agriculture's risk diversification needs, with inefficient services and complex claims processes that demotivate farmers. High payout rates, moral hazard, and adverse selection further concentrate underwriting risks and financial pressures on insurance companies. Catastrophe bonds offer a solution by transferring insurance market risks to the capital market, easing government financial burdens and providing high-yield, low-risk investment opportunities.

This paper proposes pricing comprehensive disaster agricultural catastrophe bonds for major crops, addressing the limitations of current research and market needs beyond single-event bonds. It enhances traditional pricing theory by considering multi-hazard and multi-region factors, providing a range of investment options for insurance companies and governments.

## 2. Literature Review

### 2.1. Literature review related to agricultural insurance

In recent years, with the continuous advancement of China's agricultural modernisation, agricultural insurance, as an important tool for risk management, has played an increasingly important role in safeguarding farmers' income and promoting sustainable agricultural development. Wang Li and Liu Xiaofeng's (2024) study focuses on the potential impacts of agricultural insurance in promoting common prosperity, analysing how agricultural insurance can help to narrow the income gap, which



is of great significance in achieving social equity and common prosperity; and from the perspective of regional heterogeneity, Feng Lancheng and Xing Huiru (2024) perspective, studied the impact of agricultural insurance on food security, revealed the differences in the impact of agricultural insurance on food security in different regions, and provided a basis for the formulation of regional agricultural insurance policies.

## 2.2. Literature on Catastrophe Bonds

China has made progress in agricultural insurance but is still in the early stages of developing catastrophe insurance bonds. Zhang Changli (2013) suggests that issuing agricultural catastrophe bonds could enhance the underwriting capacity of the agricultural insurance industry and foster innovation within the sector. Wang Caiwei (2021) discusses the legal aspects and regulatory improvements for catastrophe bond business, offering legal and regulatory support for the industry's healthy growth. Qiu Feng (2022) examines international practices in catastrophe bond development and its implications for China, highlighting the role of catastrophe insurance in risk management by dispersing losses and complementing the traditional insurance market. Gao Zhongqin (2019) delves into the theoretical mechanism of catastrophe insurance securitisation and suggests strategies for its development in China, emphasizing its significance in freeing up capital, increasing insurance companies' risk underwriting capacity, and facilitating the integration of financial and insurance markets.

## 3. Empirical Model Construction

### 3.1. Introduction of relevant theories

This paper constructs a comprehensive catastrophe bond pricing model based on the Copula function and the Wang two-factor model, using the Copula function to verify the correlation between the yearly loss amount of individual crops across the country and the loss amount of the disaster among the three major crops, and to simulate a 10,000-year event set based on the comprehensive disaster loss amount of each of the three major crops as a way of measuring the bond triggering conditions. The Wang two-factor model is used to measure the bond price and provide relevant suggestions for insurance companies to diversify risks by comparing the corresponding reinsurance premiums, which provides a reference for reducing the difficulty of risk assessment, solving the problem of lack of data, and reducing the risk of adverse selection.

### 3.2. Data sources and statistical descriptions

**Table 1** Statistics on the three major crops at the national level

	average value	median	mode	variance	standard deviation
rice	2586104939.72	3712394417	none	$1.58 \times 10^{16}$	3978496556.15
Wheat	1,338,498,448.725	1188173488.5	none	$1.12 \times 10^{15}$	1,059,000,000
Corn	2177806896.64	2564571799	none	$1.61 \times 10^{18}$	1265078214.77

Data from the agricultural and rural statistical yearbook was collected for the three major crops from 1990 to 2022, including sown area, total sown area, and the total area affected by disasters, allowing us to calculate the disaster loss area for each crop. Additionally, using the national average purchase prices from the Henan Provincial Bureau of Grain and Material Reserves and the 2024 National People's Congress proposal, we can determine the disaster loss amount for each crop by combining the loss area with the purchase price. Analysis of the averaged annual loss data reveals that wheat has the highest total loss nationwide, corn experiences the most fluctuation, and rice has a moderate loss level in comparison. In the detailed solution, due to significant data gaps in rice yield in Qinghai and

wheat yield in Hainan, these are excluded, and other missing values are omitted to ensure data accuracy.

#### 4. Empirical measurements and analysis of results

To create a simulation dataset for the damage loss amounts of three major crops nationwide, the process begins with fitting a marginal distribution to the data to identify a suitable distribution for simulation. Then, Copula fitting is used to verify the correlations between the damage loss amounts of each crop in different provinces. Following this, Copula fitting is applied again to verify the correlations among the damage loss amounts of the three crops. The final step involves using Monte Carlo simulation to generate a 10,000-year event set, which is then rank correlated. This rank-correlated data from the 10,000-year event set serves as the input for Wang's two-factor model. The simulated data is used to calculate the pricing of catastrophe bonds in the final pricing model, determining the bond's coupon price.

##### 4.1. Edge Distribution Fitting

First of all, the marginal distribution of the data is fitted to select the appropriate function to portray the characteristics of the data, through a comparative analysis found that the lognormal distribution and the Weibull distribution are the two distributions with the best fitting effect, through the observation of the three sets of data in the rice, wheat, maize data fitted with a lognormal distribution of the data of the lognormal distribution of the lognormal mean and the lognormal standard deviation, the AIC value and the BIC value of this paper can be seen, the three sets of data dispersion is smaller, the fitting effect is better;

**Table 2** Lognormal parameter estimation table

	rice	wheat	corn
logarithmic mean $\mu$	0.15	0.29	0.23
logarithmic standard deviation $\sigma$	0.15	0.20	0.16
AIC	1179.606	1260.929	429.121
BIC	1182.537	1263.922	429.726

For the other set of data fitted with the Weibull distribution, the shape parameter (Shape- $\beta$ ) can be used to initially judge the approximate shape of the distribution; the scale parameter (Scale- $\eta$ ) is used to judge the degree of dispersion of the distribution; the larger the scale parameter is, the smaller the variability of the data is, which indicates that the variability of these three sets of data is small; from the AIC value, BIC value, we can see that the fitting effect of these data is better;

**Table 3** Weibull parameter estimation table

	rice	wheat	corn
Shape- $\beta$	1.57	0.68	1.89
Scale- $\eta$	41027560	65473457	821588143
AIC	1173.264	1263.265	427.057
BIC	1179.196	1266.258	427.662

##### 4.2. Copula modelling between provincial loss amounts for each of the three major crops

In this paper, the VineCopula method was applied to aggregate the dataset to a national scale. By comparing the coefficients of variation between marginal distribution fitting and Copula fitting, the

Copula method demonstrated superior performance, indicating the presence of correlations in the loss amounts of the same crop across different provinces. This supports the choice of Copula as the fitting tool. To validate the model's predictive power, rank correlation analysis was performed. The simulated data, when ranked, showed a high degree of consistency with the real data in terms of rank order. The model effectively captures not only the marginal characteristics of the data but also the interdependencies between different provinces for each crop.

### 4.3. Copula modelling between loss amounts for the three major crops

By fitting lognormal and Weibull distributions, this paper evaluates the effectiveness of the two distributions in fitting the loss amount data for rice, wheat and maize. The fitting results show that for most years, the lognormal distribution provides a better fit, and the Weibull distribution was chosen for the remaining datasets. To construct a joint distribution model, the VineCopula method, which is a flexible and computationally efficient Copula model, was used in this paper. With the RVineStructureSelect function, this paper selects the best Copula structure and uses the RVineMatrix function to construct the Copula model;

**Table 4** Two Distribution Parameters

	Weibull distribution	log-normal distribution
Shape- $\beta$	4.46	/
Scale- $\eta$	84541288275	/
AIC	1662.75	1674.31
BIC	1665.74	1677.30

The model fitting results show that both the marginal distribution parameters and the Copula model parameters are statistically significant. The goodness-of-fit metrics, such as AIC and BIC, indicate that the selected model captures the characteristics of the data well. The amount of rice loss, the amount of wheat loss, and the amount of maize loss are set as variable 1, variable 2, and variable 3, respectively, and the parameters related to the results of their copula runs are as follows:

**Table 5** Table of copula parameters

variable name	Copula typology	Copula corresponding parameter	$\tau$ variant	$\beta$ variant
1and2	t-copula	t=-1.66	none	-0.26
2and3	Frank-copula	Shape=6.67 Scale=1.57	Upper=0.55 Lower=0.24	none
1and3	Gumble-copula	none	none	none

We have successfully developed a C-vine Copula model to capture the dependency among three variables, creating a closed chain structure with each variable linked in sequence. Utilizing this model, 10,000 data points were simulated and compared against real data, showing similarities in mean, standard deviation, and coefficient of variation, which confirms the model's validity. To further validate the model's predictive capability, rank correlation analysis was conducted. By rank ordering, the simulated data were matched with real data to evaluate the model's effectiveness in forecasting extreme loss events. By integrating marginal distribution fitting with the Copula model, a joint distribution model for multi-crop loss amounts was established. This model not only reflects the individual loss amount characteristics of each crop but also effectively captures their interrelationships.

#### 4.4. Catastrophe Bond Pricing Model

This paper addresses the risk of principal loss in natural disasters by proposing two types of bonds: principal and interest risk bonds, and interest risk bonds. Utilizing data from the State Financial Supervision Bureau, the paper establishes a survival function to simulate the probability of exceeding losses under an 84% coverage ratio for major crops in China's agricultural insurance. The catastrophe bond pricing model incorporates parameters such as the bond's starting line, par value, risk-free interest rate, yield, and maturity. The model uses a 10,000-year event set loss amount based on the Copula function to determine individual starting lines, a 1.61% one-year treasury bond yield as the risk-free rate, and a 2.67% yield for the catastrophe bonds. Given the popularity and higher issuance interest rates of medium-term bonds, the paper selects maturities of one, three, five, and ten years for the catastrophe bonds. Under different trigger amounts (\$30 billion, \$38 billion, \$45 billion, \$50 billion, and \$55 billion), the prices of one-year principal and interest risky bonds and three-year, five-year, and ten-year interest risky bonds are shown in the following table:

**Table 6** Bond Price Calculations

Trigger value (\$ billion)	One-year principal and interest risk-based bonds (\$)	Three-year interest-risk-based bonds (\$)	Five-year interest-risk-based bonds (\$)	Ten-year interest-risk-based bonds (\$)
300	89.27	106.79	111.15	121.44
380	96.76	107.76	112.72	124.47
450	99.90	108.16	113.39	125.75
500	101.19	108.33	113.66	126.27
550	102.09	108.44	113.85	126.64

The price of a one-year principal and interest risk-based bond rose to \$102.09, indicating that higher potential losses necessitate a higher bond price to cover the risk. The three-year interest-risked bonds' price movement to \$108.44 is relatively stable, reflecting the consistent nature of interest rate risk over time. Prices for five-year and ten-year interest-risk-based bonds increased to \$113.85 and \$126.64 respectively, demonstrating the compounded effect of long-term interest rate risk. The differences in bond prices are primarily due to factors such as bond maturity, trigger value, and the level of risk involved. The risk diversification benefits of catastrophe bonds are compared to reinsurance by simulating the premiums for equivalent reinsurance under various conditions, highlighting the comparative effectiveness of catastrophe bonds in risk management.

**Table 7** Comparison of Catastrophe Bonds and Reinsurance

	Purchase denomination (yuan)	Purchase term (years)	Equivalent reinsurance premiums
One-year principal and interest risk-based bonds	104.57	1	7.97
Three-year interest risk-based bonds	101.64	3	8.45
Five-year interest risk-based bonds	101.64	5	8.31
Ten-year interest risk-based bonds	101.64	10	8.00

The calculations suggest that catastrophe bonds can be an effective risk-hedging tool to help insurers manage catastrophe risk. In a low-interest-rate environment, long-term interest-risk bonds may be more attractive than reinsurance because they provide more stable and substantial inputs than reinsurance.

## 5. Conclusions and recommendations

### 5.1. Conclusion of the study

The paper's research is divided into three stages: Initially, it calculates the loss amount for the three major crops from 1990 to 2022 using sown area, affected area, and average purchase price to assess disaster-induced crop losses. Subsequently, it uses the Copula function to model data, simulating a 10,000-year event set to validate the feasibility of national agricultural catastrophe insurance through rank correlation. Finally, the Wang two-factor model is applied to simulate data to establish pricing for various catastrophe bonds. The study reveals that bond prices correlate positively with trigger values, with the ten-year interest-risk bond priced higher than the one-year principal-and-interest risk bond. Factors influencing price differences include the time value of money, bond liquidity, market interest rates, issuer credit, and government policies. When comparing bond prices to reinsurance premiums, the one-year bond and the ten-year bond both have a purchase price of \$104.57, with premiums of \$7.97 and \$8.00, respectively. This suggests that long-term interest-risk bonds are a more stable investment option for insurers compared to reinsurance, particularly in a low-interest-rate environment.

### 5.2. Recommendations

To enhance the agricultural catastrophe bond issuance environment, the paper suggests policy support with tax incentives and subsidies to lower issuance and purchase costs. It also calls for cooperation between financial institutions and agricultural producers and for the strengthening of regulatory bodies' credibility and professionalism. Additionally, it emphasizes the need for improved systems and regulations to ensure a favorable and risk-controlled issuance environment. For a robust catastrophe bond market infrastructure, the paper recommends bolstering the capital market to attract investors and stimulate market growth. It also stresses the importance of a comprehensive catastrophe database for accurate pricing of risk management products and the need for professional training. Lastly, it advocates for insurance companies to engage in international cooperation to adopt advanced risk management practices and enhance the catastrophe market infrastructure.

## References

- [1] Zhang Yuzheng, Li Zhongqiu. Integration of modern business and agricultural insurance: opportunities and challenges [J]. *Modern Business*, 2024, (09): 150-153. DOI: 10.14097/j.cnki.5392/2024.09.040.
- [2] Ding Shaoqun, Zhang Junyi. Mechanisms and policy recommendations of agricultural insurance on the resilience of agricultural industry development [J]. *China Insurance*, 2024, (04): 6-9.
- [3] LONG Wenjun, BAO Yuehong. Agricultural insurance to ensure national food security [J]. *China Finance*, 2024, (07): 68-69.
- [4] Zheng Jun, Zhuang Chunliu. Agricultural insurance, agricultural technology progress and agricultural green development [J]. *Journal of Chengdu University (Social Science Edition)*, 2024, (02): 59-80.
- [5] WANG Li, LIU Xiaofeng. Research on the impact of agricultural insurance on commonwealth [J]. *Journal of Anhui University (Philosophy and Society Edition)*, 2024, 48(02): 131-141. DOI: 10.13796/j.cnki.1001-5019.2024.02.015.
- [6] Feng Lancheng, Xing Huiru. Regional heterogeneity effect of agricultural insurance on food security [J]. *Heilongjiang Grain*, 2024, (01): 152-154.
- [7] Qiu Feng. International practice of catastrophe bonds and its inspiration to China [J]. *Hebei Finance*, 2022(09): 35-41. DOI: 10.14049/j.cnki.hbjr.2022.09.002.
- [8] Yang Q, Liu S. Synergistic Effect of Agricultural Insurance and Agricultural Credit on Agricultural Economic Development [J]. *Agricultural & Forestry Economics and Management*, 2024, 7(1):

- [9] Senapati K A. Do Farmers Value Insurance Against Extreme Droughts and Floods? Evidence from Odisha, India[J].Global Business Review,2024,25(3):561-584.
- [10] Li Y,Fan Bei,Liu Juan. Research on the design and pricing of multi-event-triggered catastrophe bonds:Taking China's typhoon bonds as an example[J]. China Soft Science,2012(03):41-48.