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Copula-Based Rate Determination of Crop Revenue Insurance

A Case Study of Early Indica Rice in Hu'nan Province

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ABSTRACT

A nonparametric kernel density distribution function was constructed based on the yield and price of early indica rice in Hunan Province from 1949 to 2019 in this paper. On this basis, Copula nonparametric method is employed to determine the most effective joint distribution function of price and unit yield through root mean square error (RMSE), and Monte Carlo simulation method is adopted to calculate the pure premium rate of revenue insurance. Results show more revenue insurance and lower pure premium rate compared with the current rice yield insurance. The inclusion of revenue insurance into financial subsidies is proposed accordingly to accelerate the pace of expansion.

Keywords: *agricultural risk management, revenue insurance pricing, Copula, early indica rice*

I. INTRODUCTION

Crop farming serves as an important part in China's agricultural economy, with grain prices, such as rice, wheat and corn, accounting for 3.07% of the CPI. The change of rice price brings forth that of grain price, animal product price and the overall price level of society, which undermines farmers' income and social and economic stability. Given meteorological disasters, diseases, insect pests and other natural disasters, the rice yield fluctuated in some areas. However, its price has generally risen year on year, which is largely explained by the incentive effect of China's grain price subsidy policy, that is minimum purchase price. Since the implementation of minimum purchase price policy in major grain-producing areas in 2004, it has failed to meet the expected income of farmers and the average income of the society, and the policy effect is diminishing though the price has been raised year by year. First, the fragmentation of land management stymies the role of pepper-spray-styled grain price subsidy policy in promoting farmers' income, failing to stabilize their income. Secondly, the grain price subsidy policy restricts land transfer to a certain extent and hinders the formation of moderate scale operation. Third, given the substantial increase in grain production costs and the support of government policies, China's grain prices have been mounting in recent years and gradually exceeded international one. This directly results in the entry of mass foreign low-priced rice into China, and huge downward pressure on domestic grain prices, which affects farmers' grain income and national food security. It's no exaggeration to say that current grain price policy can no longer meet the needs of grain production and agricultural development. China's agricultural subsidy policy has entered an important adjustment stage, and existing protective purchase price is gradually giving way. The No.1 Document of the CPC Central Committee since 2014 clearly stated that China's food security should be elevated as a policy, and the grain price formation mechanism should be improved while farmers' benefits be protected. Continuous liberalization of grain prices is bound to greatly increase the price risk faced by farmers. In addition to the original output insurance, agricultural products insurance should fully consider the risk of price fluctuations, so the promotion of income price insurance has been imperative.

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II. LITERATURE REVIEW

Federal Crop Insurance Corporation (FCIC) launched revenue insurance products in 1996 to allow farmers to cope with output risks and price risks. In 2014, revenue insurance premiums accounted for 81.5% of all agricultural insurance premiums in the United States, up from 8.5% in 1996, and more than 90% of the total amount insured. (Zhu Shenghao, 2016) There exist many types of revenue insurance, including

Actual Income History (ARH), Income Protection (IP), Revenue Assurance (RA) and Group Risk Income Plan (GRIP). They are different in insurance category, applicable region and rate determination, among which rate determination depends on data source, marginal distribution function selection and connection function.

Thanks to the developed futures market of agricultural products, the price data of revenue insurance products in the United States make full use of the price discovery function of futures market and measure the risk of price changes based on futures price data. For example, the monthly average of February futures prices for November delivery on the Chicago Board of Trade between 1959 and 2007 is selected as the basis of price data. However, price data are rarely based on futures market given China's existing financial market, and the monthly data of factory price of grain and oil information center (Zhang Qiao, Wang Ke, et al., 2015) or the Wenhua Financial and economic price index are mostly used (Xie Fengjie, Wang Erda, Zhu Yang. 2011). In terms of yield data, the United States generally adopted the yield per unit area before harvest as futures price data, while the data of yield per unit area after harvest are used in China. Risk analysis based on time series, usually quadratic polynomials and autoregressive moving averages, requires a de-trending process due to long-term price or output growth resulting from time change and external technological advances (Ker AP and Goodwin BK, 2000).

Risk measurement based on de-trending data is a key step in determining revenue insurance rates. It is generally believed that the crop output conforms to the negative skew distribution, and the price generally follows the high kurtosis and fat tail distribution. Burr, Gamma, and Beta distribution can be considered for crop output (Ker AP, and Coble K. 2003; Sherrick, BJ, et al. 2004; Ramirez OA, Misra, S, and Field, J. 2003) , and Lognormal distribution (RA plan) for price risk. A-D, K-S and Chi-square test can be adopted for model optimization, and corresponding statistical tests can also be constructed according to kullback-beibler and other information criteria (Voung, 1989).

In general, price and output are negatively correlated. The distribution functions of the two are not consistent, so it is difficult to construct their joint distribution function via traditional multivariate normal distribution. The Copula function constructs joint distribution of multidimensional random variables through edge distribution and correlation structure, which is more flexible (Dmitry Vedenov, 2008). Powel Kobus (2013) constructed yield function with normal distribution on the edge, a wheat price function with a Burr distribution on the edge, and a logarithmic normal price function on rape, and connected the Gaussian Copula function to determine the revenue insurance rates of 378 farms in Poland. Tejeda H. A and Goodwin B. K connect price function of Burr distribution and yield function of Beta distribution through Flank Copula and normal Copula to determine the revenue insurance rates for corn and soybeans in the United States.

Due to the lack of statistics of farmers' yield per unit area in China, the current distribution of yield per unit area is analyzed with time series. Since 1949, there are only 71 statistical data of the year of yield per unit area, and insufficient data may be encountered when fitting its distribution function through parametric method. In addition, the parameter form of distribution model should be assumed before using the parameter method for distribution fitting, which may ignore relevant information of the data itself. The past experience and theory show that there is often big gap between the assumption of parametric model and the actual physical model, and the results are not always satisfactory. Nonparametric kernel density estimation can significantly offset the lack of data [4], discard the parameter selection, and fit the distribution features such as thick tail and bias (Goodwin B.K, Ker, A.P, 1998).

III. RESEARCH METHODS AND DATA SOURCES

A. Copula function

Copula functions can construct joint distributions with variables of different edge distributions. For example, a two-dimensional random variable. The two-dimensional random variables X and Y are assumed to have marginal distributions F(x) and G(y), and their joint distribution is H(x, y). According to Sklar's theorem, there is a unique Copula function C that makes $H(x, y) = C(F(x), G(y))$.

Copula function C is essentially a binary joint distribution function of X and Y, random variables whose edge distribution is F(x) and G(y). Similarly, Copula can be extended to multi-dimensional joint distribution above two dimensions. The Copula function mainly includes Archimedean Copula function and elliptic Copula function, among which the former covers Gumbel Copula, Clayton Copula and Frank Copula, while the latter Gauss Copula and t-Copula. Archimedean Copulas is composed of different generators, ϕ, and there is a parameter θ hidden among them. The linear parameter, ρ, is an important parameter of Gauss Copula and t-Copula. The tail correlation of multiple variables described by different Copula functions is different.

The Copula function parameters were estimated as follows: firstly, Kendall coefficient τ of the random sample was calculated according to the following formula:

$$\tau = \sum_{i<j} \frac{sign[(x_i - x_j)(y_i - y_j)]}{\frac{n(n-1)}{2}}$$

$x_i \le x_j$ Where: n is the random sample size; $1 \le \mathrm{i}, j \le n$, when and $y_i \le y_j$, are met, sign = 1, otherwise sign = -1.

The Gumbel Copula, Clayton Copula and Frank Copula parameters were calculated based on the relationship between θ and Archimedean Copula. The parameters of Gauss Copula and t-Copula functions were calculated based on the relationship of τ and ρ.

y_k The Copula function was tested by graph analysis. RMSE, the root mean square error between the theoretical value calculated by the empirical Copula function and the measured value of the actual Copula function, is used to evaluate the fitting error. The smaller the RMSE, the better the function fit. If the combined measured values of random variables X and Y with a sample with the capacity of n are and x_k, the empirical Copula function Ce is:

$$c_e(\frac{i}{n}, \frac{j}{n}) = \frac{a}{n}$$

$x(i)$ i j a Where: $1 \le k, \mathrm{i}, j \le n$ is the value after arranging $y(j)$ from small to large, $x_k \le x(i), y_k \le y(j)$ is the value after arranging x from small to large, while is the number of joint measured values that also satisfy y.

The RMSE formula is as follows:

$$RMSE = \sqrt{\frac{1}{n} \sum_{t=1}^{n} [p_c(i) - p_o(i)]^2}$$

$p_o(i)$ Where n serves as the sample size, the measured probability of empirical Copula function, and $p_c(i)$ the probability calculated from Copula function adopted.

B. Data source and processing

$p(t)$ The yield data of early indica rice from 1949 to 2019 in Hunan province were obtained from Hunan Statistical Yearbook. The price data is the monthly price data of national agricultural products market from February 2014 to December 2019, which is obtained from the Yearbook of China Agricultural Product Price Survey over the years. The statistics and analysis of time series must ensure that it is stationary, and stationary time series can guarantee overall randomness, which is the premise to extract data. The time series of yield per unit area and price increases obviously in the long run, not in the stationary one. The original data are all unstable sequences and must be processed. In view of the role of time change, agricultural technological progress, improvement of agricultural production facilities and improvement of production efficiency of agricultural workers on early rice yield per unit area and that of inflation on early rice price, it is necessary to de-trend the growth of data. The quadratic polynomial with time as explanatory variable was used to carry out regression analysis on yield per unit area and price data, and the trend output and trend price $q(t)$ were obtained.

$$q(t) = 2007.74 + 54.38 * t + 1.62 * t\text{^}2 + 0.025 * t\text{^}3$$

$$p(t) = 1.701 + 0.0248 * t - 0.00012 * t\text{^}2$$

$\hat{\mathrm{y}}_t$ Yield per unit area of each year is adjusted to the same year of production to ensure that comparisons are made at the same level of productivity. In this paper, it is adjusted to 2019. Assuming that the original yield per unit area is , the adjusted yield per unit area y_t is:

$$\hat{\mathrm{y}}_t = \mathrm{y}_t + q(71) - q(t)$$

The same is true of the way price data are adjusted. The unit root method was used to test the stability of the adjusted unit yield and price data, and the results were shown in "Table I".

TABLE I. RESULTS OF AN UNIT ROOT TESTING

Sequence	Test form (C, T, K)	ADF statistics	Critical value (5%)	P value	Conclusion
Per unit yield	C, T, 10	-3.2625	-2.9069	0.0208	Stable
Price	C, T, 10	-3.0573	-2.9155	0.0359	Stable

a. C represents the constant term, T represents the trend line, and K represents the lag order. P value is the probability of accepting the null hypothesis.

IV. RATE DETERMINATION PROCESS AND RESULTS

The data of skewness and kurtosis are obtained by statistical analysis of the adjusted unit yield and price, as shown in "Table II".

TABLE II. STATISTICAL ANALYSIS OF ADJUSTED DATA

Sequence	Kurtosis	Skewness	J-B value	P value	Conclusion
Per unit yield	2.4079	0.2250	1.5212	0.4674	Nonnormality
Price	1.7856	-0.0756	4.1187	0.1275	Nonnormality

J-B statistical analysis shows that it is not a normal distribution, so the non-parametric kernel density method mentioned above is considered to be used for distribution fitting.

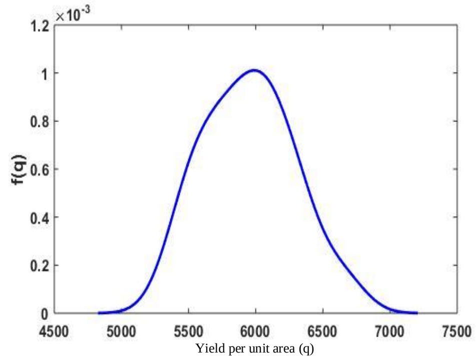

Fig. 1. The kernel density probability function of yield per unit area.

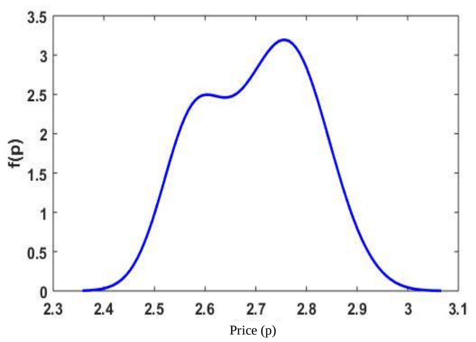

Fig. 2. The kernel density probability function of the price.

TABLE III. KERNEL DENSITY ANALYSIS OF YIELD AND PRICE

Sequence	Kernel	Mean value	Window width
Per unit yield	Gauss	5951	162.3262
Price	Gauss	2.700	0.0565

After the distribution function of unit yield and price is obtained, the binary histogram of price and unit yield can be drawn to calculate the value of the original data on the distribution function, and the distribution function value can be used as the original value of Copula function.

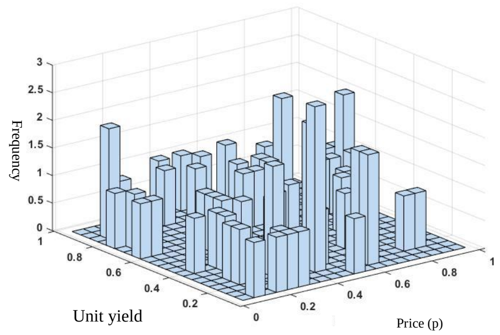

Fig. 3. Binary frequency graph of unit yield and price.

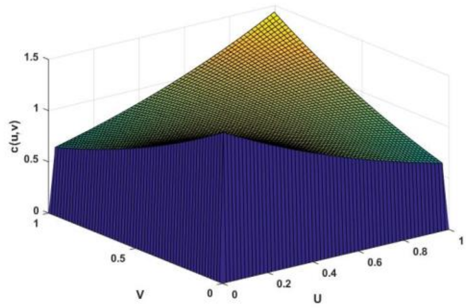

Fig. 4. The Frank Copula function graph of unit yield and price.

The binary frequency histogram shows that the tail correlation between price and unit yield is not particularly obvious, and the tail correlation coefficient is not the same as that of the bottom tail. Therefore, three commonly used Archimedean Copula functions were selected: Frank Copula function, Clayton Copula function and Gumbel Copula function, to estimate the joint distribution of early rice yield and price, and two-step maximum likelihood method is adopted. The estimated results are shown in "Table IV". Empirical Copula function was used to evaluate the merits and demerits of model fitting. The Frank Copula function was adopted as the joint distribution function of rice yield and price in Hunan province according to the minimum square Euclide distance.

TABLE IV. KERNEL DENSITY ANALYSIS OF YIELD AND PRICE

Sequence	Kendall correlation coefficient τ	Parameter θ	RMSE
Frank Copula	0.0961	0.8717	0.0307
Clayton Copula	0.1172	0.2656	0.0318
Gumbel Copula	0.0736	1.0794	0.0324

The risk of yield per unit area or price can be calculated directly by integrating the formula of rate determination with Gaussian kernel function. However, even the joint distribution of unit yield and price is obtained with the help of Copula function, it is difficult to find the analytic expression of distribution function of income: the product of the duo. Monte Carlo simulation method is used to calculate the rate of revenue insurance. Firstly, according to the selected Frank Copula function, two groups of random sequences U and V are generated as the distribution values of unit yield and price. Then the original function value of the random sequence is calculated based on the edge distribution of unit yield and price: $P = F_1^{-1}(U)$, $Q = F_1^{-1}(V)$, which serves as output and price. The two sets of data are multiplied to obtain 66 income samples. The average of the obtained income samples is used as the expected income value. The expected loss value is obtained by comparing the sample value with the expected income value, and the simulated revenue insurance rate is calculated according to the rate determination formula. The process is repeated 1,000 times to get revenue insurance rate through Monte Carlo simulation. "Table V" shows the results of pure rate determination for unit production, price and income.

TABLE V. RATE DETERMINATION RESULTS

Project	Distribution function	Rate	Guaranteed value
Per unit yield	Kernel density	2.29%	5951kg/ha
Price	Kernel density	4.32%	2.70 yuan/kg
Revenue	Kernel density, Frank Copula	3.24%	16068 yuan/ha

V. CONCLUSION AND POLICY RECOMMENDATIONS

A. Conclusion

The yield and price of early indica rice over the years in Hunan province were obtained and the marginal distribution function was determined by nonparametric kernel density method. The Copula function is constructed by nonparameter estimation method of Copula function, and the most suitable Copula function is determined by RMSE criterion. The Monte Carlo simulation was employed to calculate the net rate of revenue insurance and the following conclusions were obtained: according to analysis of early indica rice products in Hunan in this paper, the premium rate of revenue insurance is 3.24%, which is higher than premium rate for risk per unit area, 2.29%, but lower than premium rate for price risk, 4.32%, and of course lower than the combined rate of 6.61%. Theoretically, price risk and unit yield risk are negatively correlated, and the revenue insurance rate constructed by the joint distribution of the two should be less than the sum of that of unit yield risk or price risk. The current rice yield insurance in Hunan covers the loss of rice yield directly caused by irresistible natural disasters. The maximum amount of the insurance will be 5,400 yuan per hectare, with an insurance rate of 5%, depending on the planting period. The determined income insurance product insurance amount is RMB 16,068/ha, which is much higher than the current rice yield insurance amount, with a lower rate and wider coverage.

B. Policy recommendations

From "Exploring the revenue insurance pilot" proposed in 2016 to "Promoting the full cost and revenue insurance pilot for rice, wheat and corn" in 2020, revenue insurance for food crops has been attached great importance at the policy level. However, rice revenue insurance is only available in parts of Suzhou, Changzhou of Jiangsu and Chongzhou of Sichuan. Given the fact that existing rice revenue insurance takes materialization cost as the insurance amount, and the guarantee is poor, which cannot effectively stabilize the income of grain farmers, the experience gained from pilot project of full cost insurance in Anhui and Hubei in 2018 should be summarized as soon as possible, and the promotion of revenue insurance products to replace original yield insurance should be accelerated. The insurance amount of revenue insurance products is high, and the insurance premium is higher than the original production insurance, so the farmers cannot afford it. The one responsible for the subsidy of insurance rate of current revenue is district county government or futures exchange, undermining its further promotion. The paper proposes that the revenue insurance products should be included in policy-based agricultural insurance products of the central finance, and the three-level premium subsidy system of the central government, provinces and counties should be implemented.

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