Influence of Flexible Crop Yield Distribution on Crop Insurance Premium Rate——A Case Study on Cotton Insurance in Three Areas of Xinjiang

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Abstract Based on theoretical analysis of crop risk and premium rate setting, we take the case of premium rate setting of insurance on cotton yield in Shache County, Shaya County and Aksu City of Xinjiang. Using parametric methods and insurance actuarial technique, we select the optimal model for risk fitting of cotton yield in three areas; compare the premium rate calculated accurately under four risk distribution assumptions of cotton yield, and the rational premium rate, to analyze the impact of risk distribution of crop yield on premium rate setting. The empirical results show that the Logistic distribution is the optimal distribution for risk fitting of cotton yield in three areas; the rational net premium rate of cotton insurance in three areas is 7.62%, 6.32% and 4.96%, respectively; there are errors in premium rate setting under assumptions of normal distribution, normalized skew distribution and Weibull distribution, ranging from 0.2 percentage points to 8 percentage points. Thus, it indicates that the selection of risk distribution model of yield directly affects the accuracy of premium rate setting of crops, and the key to accurate premium rate setting of crops lies in correct selection of risk distribution model of yield.

Key words Risk distribution of yield, Premium rate setting, Model selection, Xinjiang

At the present time, as the party and the government attach great importance to issues concerning agricultural insurance, the policy-oriented agricultural insurance in China has achieved rapid development. According to statistics, 31 provinces in the mainland of China carried out the pilot work of policy-oriented agricultural insurance in 2008[1], and China's premium revenue of agricultural insurance reached 11.07 billion yuan, becoming a country with considerable premium revenue second only to the U.S.[2]. However, the agricultural risk assessment and scientific premium rate setting based on this—the basic work that needs to be urgently carried out for continuous development of the agricultural insurance, has seriously lagged behind. The domestic industry circle and academia's research on this issue is also not deep enough. The bias and error in the crop risk assessment and premium setting will exacerbate the original serious adverse selection and moral hazard problem in the agricultural insurance, having impact on continuous development of the policy-oriented agricultural insurance. Therefore, researching the characteristic of crop risk distribution model of yield and the impact of it on agricultural insurance rates, and scientifically setting the premium rate of crops, is of important practical significance to promoting the continuous and healthy development of China's agricultural insurance. Most of domestic academia's researches on the agricultural insurance are qualitative researches, largely focusing on the introduction of foreign experience, the nature of agricultural insurance, the demand for agricultural insurance, the agricultural insurance system and operational mechanism, and other macroscopic levels, lacking the quantitative empirical researches at technical level[3].

In recent years, some scholars used some parametric methods (normal distribution, normalized skew distribution) and nonparametric methods to research the distribution of agricultural risk[4-7], but the assessment of the effectiveness of these methods, and research on the quantitative relationship between risk distribution model of yield and the premium rate setting, have not yet been reported in China. The foreign studies on the agricultural insurance start early, also attaching great importance to the research of issues concerning the distribution of agricultural risk and the setting of premium rate. Many kinds of parametric and nonparametric methods are advanced for determining the distribution model of crop risk such as Weibull, Beta, and Kernel[8-11], achieving a lot of high-quality research results; although the existing research results abroad provide reference for this research, most studies fit the long-term trends in crop yield, using the first-order, second-order or third-order linear regression method, with great subjectivity in the selection of the trend equation. And there is no research on the relationship between the risk distribution of crops in China and the premium rate in sight. In the light of the actual needs for development of the policy-oriented agricultural insurance in China and the status quo of research at home and abroad, based on theoretical analysis of crop risk and premium rate setting, we take the case of premium rate setting of insurance on cotton yield in three areas of Xinjiang. Using parametric methods and insurance actuarial technique, we select the optimal model for risk fitting of cotton yield in three areas; compare the premium rate calculated accurately under four risk distribution assump-

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tions of cotton yield, and the rational premium rate to analyze the impact of risk distribution of crop yield on premium rate setting, aiming at exploring the optimal model for assessing the size and distribution of crop risk, the scientific methods for accurately setting the premium rate of crops, to promote the sustainable development of agricultural insurance in China.

1 Theoretical study

1.1 Concept and principle of the premium rate setting of crops The premium rate setting is the process of the insurers pricing the insurance products, on the basis of estimating the expected losses of the insured and determining the occurrence probability and size of losses[12]. Crop yield insurance is an important aspect of the property insurance, whose basic idea of premium rate setting is the same as that of general property insurance, namely taking the average loss rate of crop yield as net premium rate of crop insurance, adding certain security surcharge rate on the basis of net premium rate, to get total premium rate of crop yield insurance. This study only considers the setting of net premium rate. As to the setting of the premium rate, we should make rights be equivalent to obligations on the whole, follow the principles of adequacy, fairness and rationality, stability and flexibility, promoting disaster and loss prevention[13]. In terms of crop insurance, the principle of fairness and rationality is the most important basis for the premium rate setting of crops, which contains two meanings. The first is the balance of earnings and expenditure in the insurance company, that is, the balance between insurance company's total earnings and the level of total expenditure should be maintained. The second is the balance of income and expenditure of the insured, that is, each policyholder pays the same premium for the same insurance liability, and has the same opportunity to get compensation; in the long term, each policyholder's premium expenditure and compensation income should maintain basic equilibrium[14]. Therefore, the key to the rational premium rate setting of crops lies in accurately measuring the level of risk of the insured farmers, so that the premium paid by the insured farmers matches the level of risk, otherwise, it will have the problem of adverse selection.

1.2 Setting method of the premium rate of crop yield The premium rate setting of crop yield is based on the size and distribution characteristics of risk faced by crop production. At present, there are two methods for setting the premium rate of crops: the empirical premium rate method and production risk distribution model derivation method. The former refers to a method used by the insurer to estimate the agricultural premium rate in current period, according to the historical losses and experience of single farmers or regions, which is too subjective, lacking scientificity. The latter refers to a method of using statistical knowledge and probability theory to estimate the probability density function of risk of regional or personal crop yield, then using the knowledge of probability theory to set premium rate[10], which is rigorous in theory and strong in mathematical reasoning. Since the calculation results are more accurate and objective, most of the domestic and international studies on setting agricultural premium rate use this method, and our study also researches and introduces this method.

The risk of crop yield, also known as production risk, refers to the degree of deviation of the actual crop yield from the expected yield, namely the random fluctuation degree of crop yield[15], therefore, the risk of crop yield can be denoted by the fluctuation value of crop yield. Relative random fluctuation value eliminates dimension, with good comparability, which can be used to denote the size of crop production risk, having the advantage of being insusceptible to spatio-temporal impact[6]. Therefore, this study uses relatively random fluctuation value of crop yield to signify risk of crop yield.

$$y_R = \frac{y_w}{y_t} = \frac{y - y_t}{y_t} \quad (1)$$

where y is the actual crop yield; y_t is the trend value of yield; y_w is the fluctuation value of yield.

Assuming that the peasant households buy the insurance contract of yield with deductible franchise ratio, when the negative fluctuation rate of yield of the peasant households exceeds the franchise ratio, the insurance company will compensate the peasant households. Compensation I is as follows:

$$I = p_m Y_A \max\{(y_{R,C} - y_R), 0\} \quad (2)$$

where p_m is the compensation per unit determined when the insurance contract is signed (for convenience, assuming that p_m =1 yuan/kg); Y_A is the expected yield or theoretical yield; $y_{R,C}$ is deductible franchise ratio stipulated by insurance contract.

Let a be the number of insurance contract bought by the peasant households, then compensation I is also function of a, namely $I = I(a)$. Here the utility function after the peasant households buy the agricultural insurance is as follows:

$$U(\cdot) = (1-P)U(m-\pi) + PU(m-\pi-d+I) \quad (3)$$

where $U(\cdot)$ is Von Neumann – Morgenstern utility function; P is the probability of the peasant households suffering from loss; m is the initial income of the peasant households; π is insurance premium; d is the loss that the peasant households suffer from.

Assuming that there are no transaction costs, z represents other factors influencing the size of premium rate, such as information costs, then the premium can decomposed into the function of a and z, namely $\pi = \pi(a, z)$.

We derive a. When U', and the marginal utility of being insured is equal to the marginal utility of not being insured, the utility of the peasant households is the greatest. Here:

$$\frac{U'(m-\pi)}{U'(m-\pi-d+I)} = \frac{P\{I'(a) - \pi'(a, z)\}}{(1-P)\pi'(a, z)} \quad (4)$$

Namely:

$$(1-P)\pi'(a, z) = P\{I'(a) - \pi'(a, z)\} \quad (5)$$

After simplifying, we get:

$$\pi'(a, z) = PI'(a) \quad (6)$$

First, scientific and rational agricultural insurance premium should be equal to the expected loss of the peasants households $E(L)$:

$$\pi = E(L) = Y_A E\max[y_{R,C} - y_R, 0] = Y_A E(L_R) \quad (7)$$

Second, rational agricultural premium rate R should be equal to the expected loss rate of the peasants households $E(LR)$,

$$R=\frac{E(L)}{Y_A}=E(L_R)=\int_{-1}^{y_{R,C}}(y_{R,C}-y_R)f(y_R)\mathrm{d}y_R \quad (8)$$

1.3 The risk distribution model of crop yield From equation (8), we can find that the determining of the agricultural premium rate depends on the following two factors: the first is the risk probability distribution of crop yield; the second is the deductible franchise of the crop insurance contract $y_{R,C}$. The latter is pre-set in design of the insurance contract, and the insured farmers can independently choose the insurance contracts with different franchise ratios, according to their risk preferences and the bearing capacity; the former exists objectively, and when the deductible franchise is certain, the risk probability distribution of yield will become the main factor determining the agricultural premium rate, the fitting reasonableness of which directly determines the accuracy of premium rate setting results.

At present, there are mainly two methods for fitting risk of crop yield and determining risk distribution model of yield: parametric method and non-parametric method. The so-called parametric method is a method of first assuming that the fluctuation of yield follows certain distribution, then using the fluctuation data of yield to estimate the specific parameter value of this distribution. This method is most commonly used, and applies when there is a small amount of sample data. Since it needs to presume the model form in advance, there is a certain degree of subjectivity. The non-parametric method is a novel method in the world at present, and this method does not need to assume the distribution model of crop yield in advance, with some advantages such as free distribution form, loose requirements on functional form distribution assumptions and accurate calculation results, but at the same time, it poses high requirements on the quantity and quality of the sample data, and applies when there are large samples[4, 9, 15]. Whether to choose parametric method or non-parametric method when establishing crop risk distribution model of yield, needs to depend on the actual situation, and we should not treat the two methods in an undiscriminating manner. Generally speaking, if the statistical basis and the amount of data are better (less than 30 to 40 observed values), it is recommended to use parametric method; conversely, if there is a large amount of data, and we do not know the specific form of distribution, the non-parametric method will be better[12]. The history of carrying out the agricultural insurance in China is not long and the accumulation of data is not enough, so we use parametric method to fit and compare the risk distribution of crop yield.

Early studies suggest that the risk of crop yield follow normal distribution[16], but most scholars are skeptical of it. At present, foreign scholars have advanced Beta distribution, Gamma distribution, Weibull distribution, Logistic distribution, Burr distribution, lognormal distribution, hyperbolic positive and negative rotation distribution and many other parameter models, used for analyzing risk distribution model of crop yield[10]. In comparison, the domestic researches in this area lag behind, most of which comply with different ideas, assume that the risk of crop yield follows normal distribution or make the risk of crop yield follow normalized skew distribution through processing technology[5-6]. In recent years, through empirical research, some foreign scholars confirm that wrong selection of risk distribution model of yield will have great impact on the setting of agricultural premium rate, emphasizing the importance of rational selection of risk distribution model of yield. For example, the study results of literature[17] show that the premium rate set using Beta distribution and Kernel distribution is too high; the premium rate set using normal distribution and Gamma distribution is too low. Sherrick calculated the same data using Beta distribution, Weibull distribution, normal distribution and Logistic distribution, and the premium was $5.18, $4.65, $4.48 and $3.87, respectively,[18]. From the study abroad, we can find that the selection of risk distribution model of crop yield has significant impact on the setting of the agricultural premium rate, therefore, the processing way used by the domestic scholars to assume that crop yield risk follows normal distribution and normalized skew distribution, may causes errors in the premium rate calculated.

2 Empirical research

In this study, taking the case of the premium rate setting of cotton yield under 4 distribution forms (normal distribution, normalized skew distribution, Logistic distribution and Weibull distribution), in three main cotton producing counties in Xinjiang (Shache County, Shaya County and Aksu City), we conduct empirical study on the impact of selection of risk distribution model of crop yield.

2.1 Data source and processing We conduct empirical research, using the county-level data concerning cotton yield in three areas of Xinjiang during the period 1989–2006. The data in 2006 are from Xinjiang Statistical Yearbook in 2007, and the remaining years of data are from the county-level statistics database of the Chinese Ministry of Agriculture. The sample areas are located in the southwestern Xinjiang. Shache County is located in the southern Kashi, with a warm temperate continental climate; Shaya County and Aksu City are located in the eastern and central parts of the Aksu Prefecture, with a continental temperate arid climate.

Before the analysis using the time sequence data, we must conduct stationarity test of the time sequence, namely the unit root test, because if the sequence is not stationary, it means that the digital characteristics of time sequence change over time, then it is difficult to master the randomness in the time sequence as a whole, through known information of the sequence[19]. In this study, we adopt the Phillips – Peroon (PP) test to conduct stationarity test of the sequence of cotton yield in three areas. The test results show that the sequences of cotton yield in three areas are all non-stationary sequences, with time trend; when the constant term and trend term are contained, the sequences of cotton yield in three areas, at significance level of 5%, 1% and 10% respectively, reject the null hypothesis of there being unit root. So, in order to get random fluctuation value of cotton yield, we first need to accurately fit the historical trend value of cotton yield. Linear moving average method is relatively objective, which can take full advantage of

sample data information[20], so this study uses this method to conduct trend simulation of cotton yield in three areas. We refer to crop disaster industry standards set by the China Meteorological Administration as a reference[21], and make comparative analysis based on the simulation results, to select step size *k* at 11 years.

After simulating the trend of crop yield, we calculate relative random fluctuating sequence of cotton yield in three areas of Xinjiang, according to equation (1).

Table 1 Simple statistic of relative random fluctuating sequence of cotton yield in three areas of Xinjiang

Area	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation	Skewness	Kurtosis	J – B statistic	*P*//%
Shache County	–0.002 4	0.553 6	–0.381 0	0.197 1	–83.590 3	1.219 0	5.433 6	8.899 7	1.17
Shaya County	–0.023 7	0.221 4	–0.355 7	0.146 3	–6.170 2	–0.532 8	3.010 1	0.851 8	65.32
Aksu City	–0.006 9	0.216 6	–0.340 4	0.132 9	–19.383 7	–0.613 7	3.536 4	1.345 8	51.02

Note: J – B is Jarque – Bera test; *P* is the probability of making mistake after the sequences reject following the null hypothesis of normal distribution.

2.2 Establishment of risk distribution model of yield and optimal model selection This article has assumed four possible risk distribution patterns of cotton yield in three areas of Xinjiang. We can establish the risk distribution model of three areas cotton yield, merely by estimating the parameters of each model, after calculating relative random fluctuating sequence of cotton yield in three areas of Xinjiang.

In this study, we use the maximum likelihood estimation method (MLE) to estimate the parameter value of 4 risk distribution models. The reason for using MLE is that this method has good statistical properties (such as consistency, validity and invariance), which is a robust method in parameter estimation[22]. The estimated parameter value of four risk distribution models of cotton yield in three areas of Xinjiang can be shown in Table 2.

Table 2 Parameter estimation of four risk distribution models of cotton yield in three areas of Xinjiang

Area	Normal distribution		Normalized skew distribution		Logistic distribution		Weibull distribution	
	u	σ	*u*	σ	*m*	*b*	*m*	*b*
Shache County	–0.002 36	0.197 11	–0.019 03	0.208 61	–0.025 08	0.090 57	1.908 60	0.449 61
Shaya County	–0.023 71	0.146 27	–0.048 56	0.076 29	–0.015 47	0.079 52	2.151 80	0.631 57
Aksu City	–0.006 86	0.132 88	–0.029 41	0.076 30	–0.000 02	0.071 54	2.390 30	0.654 70

Note: *u* and σ are the mean and standard deviation of normal distribution and normalized skew distribution, respectively; *m* and *b* are the location parameter and scale parameter of Logistic distribution, respectively; *r* and *a* are shape parameter and scale parameter of Weibull distribution.

Existing studies abroad show that, the optimal risk distribution model of crop yield, hinges on crop characteristics and crop growth environment. We need to use simulation technology combined with statistical test for scientific choice. Based on the simulation of cumulative distribution function, we use Anderson – Darling (AD) test to select the optimal risk distribution model of cotton yield in three areas, and the test results are shown in Table 3. Table 3 shows that AD test values of the Logistic distribution are all the smallest, indicating that the relative random fluctuating sequence of cotton yield in three areas is most likely to follow the Logistic distribution, that is, the optimal selection of three areas is all the Logistic distribution. This also shows that we use normal distribution, normalized skew distribution and Weibull distribution to set the premium rate of cotton yield in three areas, and then there must be errors in the premium rate.

Table 3 Anderson – Darling (AD) test of four parameter models

Area	Normal distribution		Normalized skew distribution		Logistic distribution		Weibull distribution	
	AD value	AD value after adjustment	AD value	AD value after adjustment	AD value	AD value after adjustment	AD value	AD value after adjustment
Shache County	1.325	1.390	1.316	1.380	0.876	0.889	1.382	1.448
Shaya County	0.323	0.338	4.422	4.637	0.264	0.268	0.929	0.973
Aksu City	0.284	0.298	1.910	2.003	0.217	0.220	0.904	0.947

2.3 The premium rate setting and the impact of wrong selection of risk distribution model of yield For convenience, it is assumed that the insurance contract of cotton yield in three areas, has no franchise ratio (or the deductible franchise is equal to 0), that is, as long as the actual cotton yield of the peasant households is lower than expected yield, showing negative fluctuations, the insurance company must compensate the insured farmers. According to equation (8), we use MATLAB 7.0 mathematical software to calculate the net premium rate level of cotton yield in three areas of Xinjiang (Table 4). It can be seen that the premium rate set based on different distribution models varies and this difference is sometimes great, even if the data are the same, and the premium rate is set in accordance with actuarial principles. In this study, the rational net premium rate of cotton yield in the three areas should be 7.62% (Shache County), 6.32% (Shaya County) and 4.96% (Aksu City), but there are some errors in the premium rate set using three kinds of other distribution model, for exam-

ple, the premium rates set of the three areas using normal distribution are 7.98%, 7.1% and 5.65%, respectively, 0.4 percentage points, 0.8 percentage points and 0.7 percentage points higher than the rational level, indicating that the margin of error is much higher than the level of ordinary commercial insurance premium (for example, the basic premium rate of family property insurance is only 0.1%).

Table 4 Calculation of net premium rate of insurance on cotton yield in three areas of Xinjiang

Area	Net premium rate of insurance//%			
	Normal distribution	Normalized skew distribution	Logistic distribution	Weibull distribution
Shache County	7.98	9.31	7.62	9.21
Shaya County	7.10	6.07	6.32	14.31
Aksu City	5.65	4.74	4.96	12.14

3 Conclusions and discussions

First, the key to accurate premium rate setting of crops lies in correct selection of risk distribution model of yield. The setting of the premium rate of crops hinges in a large measure on the risk probability distribution of crop yield, and the franchise ratio of crop insurance contract . The latter is pre-set in the design of insurance contracts, and the insured farmers can independently choose the insurance contracts with different franchise ratios, according to their risk bearing capacity; the former exists objectively, and under certain franchise ratio, the risk probability distribution of yield becomes a major factor in setting the level of premium, and the rationality of its fitting directly determines the accuracy of premium rate setting results. The empirical results confirm this theoretical analysis conclusion. Through research, we find that the Logistic distribution is the optimal distribution model for fitting the risk of cotton yield in three areas; normal distribution and Weibull distribution overestimate the risk of cotton production in three areas; the processing method of normalized skew distribution overestimates the risk of cotton production in Shache County, but underestimates the risk of cotton production in Shaya County and Aksu City. It should be noted that this study conducts fitting and comparison of risk distribution model of crop yield using parametric method, and confirms that the rationality of risk distribution fitting of crop yield directly determines the accuracy of the premium rate setting results through empirical study, but it does not touch on the non-parametric method. Although the foregoing has pointed out that the non-parametric method is not applicable in this study, the conclusion of this study may have some limitations, needing to be verified in follow-up studies using the non-parametric method.

Second, the applicability of normalized skew distribution method in the premium rate setting of crops is debatable. At present, most of the domestic researches on the premium rate setting of crops assume that the risk of crop yield follows normal distribution; use normalized skew distribution method for processing, when the risk of crop yield does not meet the normal distribution. In order to test the practical effect of this method, the study regards the normalized skew distribution as a model for fitting the risk of cotton yield in three areas. From the situation in Shaya County and Aksu City (Table 4), there is the smallest error in the premium rate set by the normalized skew distribution, and it seems that the fitting effect of this method is good. However, from Table 1, we can find that the probability of Shaya County and Aksu City following the normal distribution is more than 50%; for Shache County rejecting the normal distribution assumption at significance level of 5%, the effect of normalized skew distribution is not good, which is the worst in all models. This phenomenon is contradictory with the original purpose of normalized skew distribution (The method of normalized skew distribution is a method for solving the problem that the original sequence does not follow normal distribution). Therefore, according to the empirical results, we believe that the method of normalized skew distribution may result in greater error in the agricultural premium rate, the applicability of which in setting the agricultural premium rate is debatable. Of course, this conclusion is drawn based on the empirical findings in this study, and whether this conclusion has generality, needs to be further verified, using other sample crops and expanding the sample size.

Third, we should strengthen the research on risk of crop yield, and attach importance to selection of risk distribution model of crop yield Through empirical study, we find that the Logistic distribution is the optimal distribution model for fitting the risk of cotton yield in three areas, and the rational net premium rate of cotton yield in three areas should be 7.62%, 6.32% and 4.96%, but under the normal distribution, the premium rate set is 0.4 percentage points, 0.8 percentage points and 0.7 percentage points higher than the rational premium rate, respectively; under normalized skew distribution and Weibull distribution, the premium rate set is more than 1 percentage point deviating from the rational premium rate. In comparison with the premium rate level of the ordinary commercial insurance(for example, the basic premium rate of family property insurance is only 0.1%; after plus burglary insurance, the premium rate is only 0.2%), the error arising from incorrect selection of the three kinds of risk distribution model of yield, will be large. Therefore, we believe that when designing the agricultural insurance contract and setting the premium rate, we should attach importance to the selection of risk distribution model of yield, and carefully choose the distribution model using simulation technology combined with statistical tests and other scientific and rigorous methods, rather than assume that the crop yield follows normal distribution or conduct normalized skew distribution processing, so as to abate the adverse selection problem faced by the agricultural insurance as far as possible.

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