Setting of Agricultural Insurance Premium Rate and the Adjustment Model

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Abstract First, using the law of large numbers, I analyze the setting principle of agricultural insurance premium rate, and take the case of setting of adult sow premium rate for study, to draw the conclusion that with the continuous promotion of agricultural insurance, increase in the types of agricultural insurance and increase in the number of the insured, the premium rate should also be adjusted opportunely. Then, on the basis of Bayes' theorem, I adjust and calibrate the claim frequency and the average claim, in order to correctly adjust agricultural insurance premium rate; take the case of forest insurance for premium rate adjustment analysis. In setting and adjustment of agricultural insurance premium rate, in order to make the expected results well close to the real results, it is necessary to apply the probability estimates in a large number of risk units; focus on the establishment of agricultural risk database, to timely adjust agricultural insurance premium rate.

Key words Agricultural insurance, Premium rate setting, Premium rate adjustment

With the implementation of the premium subsidy policy of central budget in 2007 and 2008, the agricultural insurance has developed by leaps and bounds in China's pilot provinces. Government's premium subsidies for various regions should be in line with their risk level, and premium rate level, so that the subsidies are scientific, fair, and reasonable, achieving the purpose of promoting utilization efficiency of premium subsidies. Therefore, it is necessary to set the appropriate premium rate according to the risk level of various regions, in order to provide a reference for the formulation of government premium subsidy policy and other policies for supporting agriculture, provide technical support for the healthy development of agricultural insurance in China.

At present, the domestic studies on the setting of agricultural insurance premium rate are mainly focused on non-parametric kernel density method. Wang Lihong, *et al*. established the method system of regional crop premium rate setting, to estimate the risk loss of corn yield in Anguo City, Hebei Province, during the period 1980 – 2004; set the net premium rate[1]. Chen Xinjian, *et al*. took the non-parametric kernel density information diffusion model as the core, and used the method of cluster analysis under the leading indicators, to conduct risk zoning of rice production cities and counties in Hubei Province, and set the net insurance premium rate of rice yield in areas of Hubei Province[2]. There are also some scholars using survival analysis method (SAM) to set the crop insurance premium rate. As to the setting of net agricultural insurance premium rate, the traditionally used method is parameter estimation method. Under the conditions of following normal distribution, the premium rate is determined by the mean and variance of the distribution[3]. When the sample size is sufficiently large, the calculation of expected losses under the normal assumption can be simplified[4]. In order to make the premium rate associated with the history of crop production, the above normal method is converted to the actual production history method (APH method). On the basis of normal distribution, Tuo Guozhu, *et al*. set regional premium rate under unified insured amount[5]. Using the non-parametric kernel density method, Liang Laicun compared the net premium rate setting methods of China's grain insurance[6]. Zhou Yan, *et al*. used the non-parametric kernel density method to research risk zoning of agricultural catastrophe insurance and premium rate setting[7].

On the basis of the above study, we analyze the setting principle of the agricultural insurance premium rate, and use the Bayesian model to analyze the adjustment of agricultural insurance premium rate.

1 The setting principle of agricultural insurance premium rate

1.1 Mathematical model for the setting of agricultural insurance premium rate The setting of agricultural insurance premium rate follows the law of large numbers. In probability theory, the law of large numbers (LLN) is a theorem that describes the result of performing the same experiment a large number of times. According to the law, the average of the results obtained from a large number of trials should be close to the expected value, and will tend to become closer as more trials are performed. It is an important mathematical basis for the operation of agricultural insurance.

1.1.1 Chebyshev law of large numbers. Assuming that X_1, X_2, $\cdots$, X_n are independent random variable sequences, having the same mathematical expectation and variance: $EX_n = \mu$, $V_{ar}X_n = \sigma^2 (n = 1, 2, \cdots\cdots)$, then for any $\varepsilon > 0$:

Received: June 30, 2012 Accepted: August 15, 2012

Supported by National Excellent Doctoral Dissertation Cultivation Fund Project, Hunan Agricultural University (GYB201003).

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$$\lim_{n\to+\infty} p\left(\left| \frac{1}{n}\sum_{k=1}^{n} X_k - \mu \right| < \varepsilon \right) = 1$$

Applying this rule to the operation of agricultural insurance can explain its meaning.

Assuming that there are n farmers, and they insure n independent subjects at the same time; X_n, a random variable, signifies the loss of each subject, and the expected value of X_1, X_2, $\cdots$, X_n is equal, that is:

$$EX_1 = EX_2 = \cdots = EX_n = \mu$$

If we calculate the net premium in accordance with the expected value of losses that the agricultural insurance subject may suffer, and regard each X_n as the actual loss, it can be clearly known that each farmer's actual loss X_n is in general not equal to the expected value of losses μ, but according to the law of large numbers, as long as the amount of insured subjects is large enough, the net premium paid by the insured μ is almost equal to the per capita loss $\frac{1}{n}\sum_{k=1}^{n} X_k$.

This conclusion, in turn, indicates how the insurer collect the net premium, that is, only when the net premium paid by each farmer is equal to the expected value of his losses, can the balance in insurer's income and expenditure be ensured on the whole.

1.1.2 Bernoulli law of large numbers. Assuming that the event A happens with the probability P in one experiment. Using nA to denote the number of occurrences of event A in n independent repeated experiments, for any positive number $\varepsilon > 0$:

$$\lim_{n\to+\infty} p\left(\left| \frac{n_A}{n} - p \right| < \varepsilon \right) = 1$$

Bernoulli law of large numbers is the special case of Chebyshev's law of large numbers. In Chebyshev law of large numbers, let each Xn be the random variable following 0 – 1 distribution, namely:

$$P(X_n = 1) = P$$

Let $n_A = X_1 + X_2 + \cdots\cdots + X_n$, then Bernoulli law of large numbers can be derived by Chebyshev law of large numbers.

Bernoulli law of large numbers shows that the frequency of occurrence of event is of stability, that is, when the frequency of experiments is very high, the frequency of occurrence of event deviating greatly from its probability is unlikely. This law is the mathematical basis for using the frequency to interpret probability, which is of great significance to using statistics to estimate the probability of losses.

In the computation of agricultural insurance, first it can be assumed that one certain agricultural insurance subject has the same loss probability, then using the previous relevant statistical data, one ratio can be calculated, namely the frequency of such agricultural insurance subject suffering loss. The frequency calculated is the loss probability. The loss probability calculated by this method is the estimated actual probability, with deviation from the actual probability. According to the law of large numbers, in the case of a large number of observations or long observation period, the ratio calculated will be very close to the actual loss probability. In other words, with increase in the number of agricultural insurance subject, the error between the loss probability calculated according to the frequency interpretation of the probability and the actual loss probability will be gradually reduced; the stability and authenticity in the loss probability estimated will be higher.

Therefore, the greater the number of agricultural insurance subject insured, the more accurate the insurance premium set by the insurer according to the law of large numbers, the greater the financial stability, and the smaller the operating risk.

1.1.3 Poisson law of large numbers. Assuming that the probability of a random event A occurring in the first test is P_1, the probability of a random event A occurring in the second test is P_2, ……, the probability of a random event A occurring in test n is P_n. Similarly, n_A is used to signify the frequency of this event occurring in n tests, then according to the Poisson law of large numbers, for any :

$$\lim_{n\to+\infty} p\left(\left| \frac{n_A}{n} - \frac{P_1 + P_2 + \cdots + P_n}{n} \right| < \varepsilon \right) = 1$$

Poisson law of large numbers demonstrates that when the number of tests increases without limit, the average probability will be infinitely close to the ratio obtained from the observed results.

Poisson law of large numbers can be used in the operation of agricultural insurance, indicating that the loss probability of each independent risk unit may be different, but as long as there are sufficient subjects, the same loss probability can still be calculated in the average sense. In order to have enough subjects to facilitate the use of the law of large numbers, we can concentrate the subjects of similar nature, to calculate an overall premium rate.

The most significant conclusion drawn by applying the law of large numbers to agricultural insurance is as follows: when the number of agricultural insurance subject is large enough, the error between the estimated loss probability calculated based on the previous statistics and the actual probability will be very small. Agricultural insurance operation uses the law of large numbers to convert uncertain quantitative relationship into certain quantitative relationship. Thus, according to the law of large numbers, we can convert the quantitative relationship uncertain for single agricultural insurance subject into the quantitative relationship certain for the set of agricultural insurance subjects.

1.2 Case study of setting of agricultural insurance premium rate-taking the case of adult sow insurance Assuming that there are 2 000 adult sows faced with the risk of death, the probability of each adult sow dying in a year is 0.2%, and the death losses of each head of sow is 1 000 yuan. Each head of adult sow dies with a small probability, but in case of death, there is a great loss for farmers. If the insurance companies organize all farmers faced with the same danger, and charge each household fixed fees (*i. e.*, pure premium P) in exchange for the insurers' bearing of death risk of each adult sow, that is, once the adult sow dies in one year, the insurer will pay a loss of 1 000 yuan caused by death of each head of adult sow, then according to statistics, 4 adult sows are predicted to die in this year, and the expected claim is 4 000 yuan. It is clear that the cost charged by the insurer for each head of adult sow $P=40$ yuan(4 000/1 000), that is, if farmers pay 40 yuan for each head of adult sow, then they can get claim of 1 000 yuan once there are dangers.

The above case illustrates that if the farmers pay 40 yuan net premium for each head of adult sow, they can get the compensation (1 000 yuan) for the death loss of each head of adult sow from the insurance company. If the insurance companies charge premium, they will assume the risk of the insured transferred to them. Now we discuss how the insurance companies manage this risk.

Assuming that the insurers have insured n independent risk units with the same danger, we use the random variables X_1, X_2, $\cdots$, X_n to denote the loss of each insurance unit, then X_1, X_2, $\cdots$, X_n are mutually independent, and have the same distribution with the random variable X. For single adult sow, incoming death is the deviation between the actual loss of X and the expected loss of EX, and we can use the standard deviation of $X\sigma_x$ to denote this deviation. If n adult sows are regarded as a whole, then the actual loss of each head of adult sow is as follows:

$$\overline{X}=\frac{X_1+X_2+\cdots+X_n}{n}$$

From the nature of expected value, we can find that $\overline{EX}=EX$. According to Chebyshev law of large numbers, when the number of the insured units n is sufficiently large, the possibility of large deviation between $\overline{X}$ and EX is very small.

We explain how insurance companies reduce the risks by calculating the standard deviation ($\sigma_{\overline{X}}$) of $\overline{X}$:

$$\sigma_{\overline{X}}=\sqrt{VAR\left(\frac{X_1+X_2+\cdots+X_n}{n}\right)}=\sqrt{\frac{n}{n^2}VarX}=\frac{1}{\sqrt{n}\sigma X}$$

This indicates that if n adult sows are regarded as a whole, then the average risks of death faced by each head of adult sow will be reduced along with increase in the number of adult sow.

The overall losses faced by the insurer are $X_1+X_2+\cdots+X_n$, whose variance is $n\sigma^2 x$ and standard deviation is $\sqrt{n}\sigma x$, and the total of death faced by all adult sows is $n\sigma x$. It is clear that $\sqrt{n}\sigma x<n\sigma x$, that is, the overall risk faced by the insurer is less than the total of death faced by all adult sows. In this sense, the insurer does reduce the risk of the uncertainty.

If we examine the coefficient of variation of total risk faced by the insurer:

$$\frac{\sqrt{Var(X_1+X_2+\cdots+X_N}}{E(X_1+X_2+\cdots+X_n}=\frac{\sqrt{n}\sigma x}{nEX}=\frac{1}{\sqrt{n}}\frac{\sigma x}{EX}$$

It can be seen that the greater the number of insured units (n), the more accurate the insurer's estimation of risk.

The above analysis shows that insurance companies must give the probability of death of each head of adult sow in advance based on previous statistics, and thus calculate the net premium. Therefore, accurately estimating the probability of risk is essential for the insurance companies.

According to the law of large numbers, when using the empirical data to predict the future risk, the insurance companies often assume that the probability of occurrence of the past events is the same as that of the future events, and the estimate of the probability of occurrence of the past events is accurate. But the probability of occurrence of the past events is often not the same as that of the future events. In fact, due to changes in a variety of conditions, the probability of occurrence of events is also constantly changing. All these lead to the inevitable deviation between actual experience and expected results. In addition, with the continuous promotion of agricultural insurance, increase in the types of agricultural insurance and increase in the number of the insured, the premium rate should also be adjusted in real time.

2 Adjustment model of agricultural insurance premium rate

Based on the above analysis, we use Bayesian principle to adjust the premium rate of agriculture, that is, based on the agricultural insurance premium rate determined by a priori information, coupled with new claims records, we use the newly acquired data to correct the original estimates, adjust and calibrate the frequency of claim and the average claim, so as to correctly adjust the agricultural insurance premium rate.

2.1 Adjustment of agricultural insurance premium rate based on Bayesian theory

2.1.1 Correction of claim frequency. In general, the agricultural insurance premium rate is adjusted by estimating the claim frequency and the average claim amount. The so-called claim frequency is the number of claims of each risk unit in the period of insurance liability, and the average claim amount is the average loss of each risk unit. According to the equivalence principle, net agricultural insurance premium should be the product of the two.

Now we consider the claim record of n copies of agricultural insurance policy. If the expected claim frequency of each copy of agricultural insurance policy is $\overline{P}$, the claim frequency is the random variable with mean of $\overline{q}$. If the claim of each copy of agricultural insurance policy is the independent random variable with mean of $\overline{m}$ and variance of σ^2, then the mean of net premium of each copy of agricultural insurance policy in entire year is $\overline{q}\cdot\overline{m}$, and the net premium needed by the insurer is $P=\overline{q}\cdot\overline{m}$.

If according to a priori information, the claim frequency q follows Γ distribution of α, β, then its density function is as follows:

$$f(\theta)=\frac{\beta}{\Gamma(a)}e^{-\beta\theta}(-\beta\theta)^{\alpha-1},\ \theta>0$$

Under the condition of $q=\theta$, the claim frequency of each copy of policy x follows the Poisson distribution of parameter :

$$p(x|\theta)=e^{-\theta}\frac{\theta^x}{x!},\ x=0,1,2,\cdots$$

Thus, Bayesian estimate of q is as follows:

$$\hat{q}=E(q|x_1,\ x_2,\ \cdots,\ x_n)=\frac{\alpha+\sum_{i=1}^{n}x_i}{\beta+n}=\frac{\beta}{\beta+n}\cdot\frac{\alpha}{\beta}\cdot\frac{n}{\beta+n}\cdot$$

$$\frac{\sum_{i=1}^{n} x_i}{n}$$

where $\frac{\sum_{i=1}^{n} x_i}{n}$ is the average claim frequency of n copies of policy, the maximum likelihood estimate of Poisson distribution parameter q, and the actual observed value of the claim frequency; $\hat{q}_B$ is to use the latter to correct the former.

2.1.2 Correction of the average claim. The average claim amount is also known as the average amount of loss, denoted by m. If under the condition of $m=\theta$, the claim amount follows the normal distribution with θ *and* σ_1^2 as parameters:

$$p(x|\theta)=\frac{1}{\sqrt{2\pi}\sigma_1}e^{\frac{-(x-\theta)^2}{2\sigma_1^2}},\quad -\infty<x<+\infty$$

According to Bayesian formula, the Bayesian estimate of m is as follows:

$$\hat{m}_B=E(m\mid x_1, x_2, \cdots, x_n)+\frac{\mu\sigma_1^2+\sigma_2^2\sum_{i=1}^{n}x_i}{\sigma_1^2+n\sigma_2^2}=\frac{\mu\sigma_1^2}{\sigma_1^2+n\sigma_2^2}+\frac{n\sigma_2^2}{\sigma_1^2+n\sigma_2^2}\frac{\sum_{i=1}^{n}x_i}{n}$$

where $Z=\frac{n\sigma_2^2}{\sigma_1^2+n\sigma_2^2}=\frac{n}{n+\frac{\sigma_1^2}{\sigma_2^2}}=\frac{n}{n+k}$.

Then: $\hat{m}_B=(1-Z)\mu+Z\bar{x}=(1-Z)E(m)+Z\hat{m}_L$

where $E(m)$ is a priori estimate of the average claim amount; $\hat{m}_L=\bar{x}=\frac{\sum_{i=1}^{n}x_i}{n}$ is the average claim amount derived through observation, also the maximum likelihood estimate of m, and the actual observed value of the claim frequency; $\hat{m}_B$ is to use the latter to correct the former.

2.2 Case study of adjustment of agricultural insurance premium rate – taking the case of forest insurance One insurance company newly sets up the forest insurance business, with the average frequency of forest disasters in this area at 0.148 as a priori information (namely $\frac{\alpha}{\beta}=0.418$), and estimates the annual average amount of loss $\mu=4\ 000$ yuan, $\sigma_1=1\ 000$ yuan, $\sigma_2=20\ 000$ yuan.

According to the experience, the insurance company is definite (95%) about the relative error between the real claim frequency and 0.148 does not exceed 25%.

As a result, as to the 2 427 copies of policy of this insurance type in the first business year, 320 claim cases occur, with the average claim amount of 4 500 yuan. In the second business year, there are 6 982 valid insurance policies, and 951 claim cases occur, with the average claim amount of 4 550 yuan. Insurance companies use the above Bayesian approach to correct the claim frequency and average claim amount.

2.2.1 Correction of claim frequency. According to the first year of operation, the claim frequency can be corrected as follows:

$$\hat{q}_B=\alpha+\frac{\sum_{i=1}^{n}x_i}{\beta+n}=\frac{64+320}{432.5+2427}=0.134$$

Then according to the second year of operation, the claim frequency can be further corrected as follows:

$$\hat{q}_B=\alpha+\frac{\sum_{i=1}^{n}x_i}{\beta+n}=\frac{64+320+951}{432.5+2427+6982}=0.136$$

According to two years of operation, the corrected claim rate is 0.012 lower than a priori claim frequency (0.148).

2.2.2 Correction of the average claim. The credibility factor of the average claim amount is as follows:

$$Z=\frac{n}{n+\frac{\sigma_1^2}{\sigma_2^2}}=\frac{320}{320+\left(\frac{20\ 000}{1\ 000}\right)^2}=0.444$$

Thus, according to the first year of operation, the average claim can be corrected as follows:

$\hat{m}_B=(1-Z)E(m)+Z\hat{m}_L=(1-0.444)\times 4\ 000+0.444\times 4\ 500=4\ 222$ (yuan)

According to the second year of operation, the credibility factor is as follows:

$$Z=\frac{n}{n+\frac{\sigma_1^2}{\sigma_2^2}}=\frac{320+951}{320+951\left(\frac{20\ 000}{1\ 000}\right)^2}=0.761$$

The average amount of claim can be further corrected as follows:

$\hat{m}_B=(1-Z)E(m)+Z\hat{m}_L=(1-0.761)\times 4\ 000+0.761\times\left(\frac{4\ 500\times 2\ 427+4\ 500\times 6\ 982}{2\ 427+6\ 982}\right)=4\ 410.2$ (yuan)

According to a priori information of claim frequency and average claim amount, the risk premium is set by insurance companies as 0.148 × 4 000 = 592 yuan. After two business years of practice, using the corrected claim frequency and average claim amount, the risk premium should be adjusted as 0.136 × 4 410.2 = 600 yuan.

With constant accumulation of data, certainty of true claim frequency and average claim amount will be getting better and better, and the premium set will become more reasonable.

3 Countermeasures and recommendations

The above analysis shows that in the setting and adjustment of agricultural insurance premium rate, in order to make the expected results be well close to the real results, probability estimates must be applied in large quantities of risk units. We should pay attention to the following two aspects:

(i) Establishing agricultural risk database. In order to accurately estimate the probability of occurrence of the event, the insurance company must master a lot of empirical data. The more the empirical data, the more accurate the estimate of the probability of occurrence of events. Once the probability of occurrence of the event is estimated, we must apply this estimate of probability in a large number of risk units, to accurately estimate the future losses.

The important part of development of agricultural insurance products is the collection and actuarial treatment of loss data. Insurance companies should collect and analyze the historical data of various types of natural disasters, meteorological data, geological data and economic environment data, to gradually

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the added value of agricultural products, so as to achieve base breeding, standardization of production, enterprise management, industrialization development, and provide high-quality, green, fresh agricultural products in conjunction with flowers and seedlings for afforestation and beautification, to the local areas, the surrounding areas and even Yangtze River Delta cities.

4.1.2 Sightseeing-based urban agriculture. In the light of the urban residents' living need of being eager to experience the feeling in countryside in their spare time, sightseeing-based urban agriculture uses the advantages of urban agriculture, such as rich resources, greenness and healthiness, and low-cost consumption, integrating leisure vacation, enjoyment of natural scenery, and experiencing of farming, in order to attract urban residents inside and outside the city to experience rural life in holiday.

4.1.3 Popular-science-based urban agriculture. It aims to build the popular-science-oriented urban agriculture base with education of agricultural knowledge as the theme, so as to build a platform for the young people in cities having little knowledge of farming to learn knowledge about agriculture.

4.1.4 Landscape-based urban agriculture. We rationally use open agricultural space within the city, and integrate diverse cultural elements into Huainan City, to develop the landscape-based urban agriculture, such as public farm, forming unique urban style and features.

4.1.5 Processing-and-service-based urban agriculture. It extends agricultural industry chain taking market as orientation, vigorously develops seed breeding of agricultural products, deep processing of agricultural products, storage and transportation of agricultural products, and other industries, and exploits value-added potential of agriculture.

4.2 Spatial framework "One Cycle, Three Areas" is focused for urban agriculture.

4.2.1 "One Cycle": urban agriculture cycle in main city zone. Around urban center and Shannan District on the point of completion, it focuses on the construction of ecological barrier and the back garden of life in downtown, to develop sightseeing-based urban agriculture, extending to the northwest, to achieve integrated development with Bagongshan Beancurd Cultural Industry Park. It focuses on building of high-quality and high-yield vegetables and special mushroom industrial park, eastern farm-fun-style cultural park, Shannan strawberries, watermelon, flowers, nursery stock base, Wabu Lake eco-tourism, farming experience, popular science education base, and Bagongshan Beancurd Cultural Industry Park.

4.2.2 "Three Areas": Panfeng Urban Agriculture Area in sinking land above exhausted mines, processing-and-service-based Fengtai Urban Agriculture Area, sightseeing-and-leisure-based Maoji Urban Agriculture Area. Panfeng Urban Agriculture Area in sinking land above exhausted mines focuses on highlighting function of ecological conservation along with governance in subsidence area, emphasizes the development of aquaculture (Cultivating marine or freshwater food fish or shellfish, and aquatic vegetables, *etc.*), characteristic fruit trees and other industries, coupled with the development of agriculture, industry, tourism and other industries; processing-and-service-based Fengtai Urban Agriculture Area, relies on the local rich agricultural resources, takes the existing deep processing industry of agricultural products as basis, constructs large production base of high-quality agricultural products, and focuses on the development of efficient and ecological production, processing, transportation industry of fresh agricultural products; sightseeing-and-leisure-based Maoji Urban Agriculture Area is based on Jiaogang Lake Scenic Spot which is national 4A level scenic spot, to develop tourism industry of urban agriculture.

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establish the empirical database. At the same time, insurance companies should strengthen the actuarial technique, to make the agricultural risk predictable and measurable as far as possible.

(ii) Timely adjusting agricultural insurance premium rate. Agricultural insurance premium rate is usually adjusted by estimating the claim frequency and average claim amount. Due to changes in various conditions, the probability of occurrence of events is also changing. All of these lead to the inevitable deviation between actual experience and expected results. In addition, with the continuous promotion of agricultural insurance, increase in types of agricultural insurance and increase in the number of the insured, the premium rate should also be adjusted in real time, so that it is more reasonable.

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