

Research Article

Research on Revenue Insurance Premium Ratemaking of Jujube Based on Copula-Stochastic Optimization Model

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Received 29 March 2021; Accepted 6 May 2021; Published 18 May 2021

Academic Editor: Ghulam Mustafa

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During the process of jujube planting, there are not only natural risks caused by natural disasters but also market risks caused by price factors. In the study, firstly, wavelet analysis method was used to stabilize the jujube yield per unit area and the jujube price from 1997 to 2018 in Aksu region, Xinjiang, China. Secondly, EasyFit software was used to fit the distribution functions of yield per unit area and price, respectively. Thirdly, the optimal Copula function which connects the marginal distribution functions and its joint distribution function was selected with the principle of “the minimum square distance from the empirical Copula function.” Finally, taking the premium rate and the insurance amount as two decision variables, the farmer’s risk minimization as the objective function, around the four constraints of functions and role of insurance, the nonspeculative nature of insurance, the sustainability of insurance, and the moral hazard factors and the farmers’ willing to participate in insurance, the Copula-stochastic optimization model was set up to determine the premium rate of jujube revenue insurance in Aksu region.

1. Introduction

“The world’s red dates are in China, and China’s red dates are in Xinjiang.” China’s jujube planting area and output rank first in the world. As the largest fruit industry in Xinjiang, the jujube industry is a new growth point of rural economy in southern Xinjiang and an important way to increase farmers’ income. However, due to the existence of natural disasters such as harmful organisms, low temperature and freezing damage, strong wind and dust, and market price, the development of the jujube industry in southern Xinjiang is directly affected. For this reason, the local governments actively explore safeguard measures. In years of production practice, the importance of agricultural insurance in the development of Xinjiang characteristic fruit industry has been gradually recognized [1].

In 2018, Xinjiang’s jujube planting area accounted for nearly 50% of China’s total, and the planting area of jujube in Xinjiang was mainly concentrated around the Tarim Basin in southern Xinjiang, and Aksu region accounted for about 20%. Aiming at the situation of rapid development of fruit industry in Aksu region, in order to ensure fruit growers’ income and prevent natural disasters, Xinjiang government launched pilot insurance policy for characteristic fruit industry in 2010. Aksu city was selected as the pilot county and city. It adopted the form of fixed insurance with an insurance amount of 15,000 Yuan per hectare, with a premium rate of 9%, covering jujube, apple, pear, etc., and the premium subsidy ratio was 65% from the regional government, 15% from the regional and municipal government, and 20% from farmers. In 2020, the policy of policy-based forest and fruit industry insurance award and subsidy benefiting the people

implemented in Aksu region, with an insurance amount of 24,000 Yuan per hectare and a premium rate of 6%. The insurance premium subsidy ratio was 30% subsidized by the central government, 35% subsidized by the autonomous region, 15% subsidized by the prefectural and county governments (no more than 5% in counties or cities), and 20% subsidized by fruit farmers. Reasonable premium rate will directly affect whether the local fruit insurance can be carried out smoothly and directly determine whether agricultural insurance can play a role in escorting the fruit industry.

Agricultural insurance is an effective mechanism for avoiding and apportioning agricultural risks, which is one of the effective tools for promoting agricultural development and one of the core ways of modern agricultural risk management [2, 3]. And, agricultural insurance belongs to the “green box policy” of WTO. Revenue insurance, which combines yield risk with price risk, has become one of the most popular types of insurance in the United States [4, 5]. Since 2007, agricultural insurance has appeared in China’s Document No. 1 of the Central Government for many consecutive years. China has appeared for many years in a row. In 2016, it was proposed to explore the revenue insurance pilot, and in 2019, it was proposed to promote the revenue insurance pilot program for agricultural products [6].

At present, the literature and materials for the determination of crop revenue insurance rate all adopt the mode of “fitting the marginal distribution functions of yield per unit area and price—selecting the optimal Copula function—Monte Carlo simulation” to determine the rate [7–17]. But the Monte Carlo simulation method is a computer simulation method, and its basic idea is to replace the probability with the frequency of random events and obtain some digital characteristics of the random variable through the generation of random number. The Monte Carlo simulation method is easy to implement and can obtain the estimate of these digital features through a large number of “experiments,” but the results are not stable and will be certain deviation with the difference of “number of experiments.”

Stochastic optimization method is an optimization method with random variables [18]. Compared with the Monte Carlo simulation method, the stochastic optimization method preserves the randomness of random variables in the model to a greater extent. By analyzing the correlation of random variables, determining decision variables, defining the objective function, and constructing the constraint conditions, the stochastic optimization model is established to obtain the final results.

2. Copula Functions

The Copula function (also known as the join or dependent function) is a function that connects the marginal distributions and the joint distribution. In 1959, Sklar first proposed Copula theory, and Elizabeth applied it in the field of crop yield insurance in 2002. In recent years, it has been gradually applied in the field of income insurance. In 2006,

Nelsen [19] gave the definition of 2-element copulas—a 2-element copula is a function with the following properties: (i) the domain of definition is $[0, 1]^2$; (ii) C is grounded and is 2-increasing; (iii) For every u and v in $[0, 1]$, $C(u, 1) = u$ and $C(1, v) = v$.

2.1. Sklar’s Theorem [19]. Let H is a joint distribution function with margins F and G . Then, there exists a Copula C such that, for all $x, y \in (-\infty, +\infty)$ and $H(x, y) = C(F(x), G(y))$. If F and G are continuous, then C is unique; otherwise, C is uniquely determined on $\text{Ran}F \times \text{Ran}G$. Conversely, if C is a copula and F and G are distribution functions, then the function H defined by $H(x, y) = C(F(x), G(y))$ is a joint distribution function with margins F and G .

Sklar’s theorem guarantees the existence and uniqueness of copulas, through which the edge distribution of crop yield per unit area and price can be connected to its joint distribution function.

3. Data Source and Processing

3.1. Data Source. In this paper, the data of planting area, output value, and yield of jujube are all from Aksu Statistical Yearbook (1998–2019), and the sample time is from 1997 to 2018. The jujube is not divided into varieties or grades. The data of jujube in Aksu region uniformly adopts the sum of the data of 7 counties and 2 cities under the jurisdiction of Aksu region as the corresponding data. According to the growth law of jujube, the grafted jujube trees will bear fruit in the same year (the second year after planting) and enter the full fruit period from the 4th year, and the yield is relatively stable from about the 6th year after planting. In this paper, the jujube output value in the current year is divided by the jujube yield as the jujube price in the current year. Since jujube is a perennial fruit tree, the calculation of yield per unit area is different from that of annual crops. The increase of nonbearing jujube trees and the reduction of the age of jujube trees is not clear, and other problems all affect the yield per unit area of jujube trees. And, considering the actual situation of Chinese jujube cultivation of Aksu region in Xinjiang and the situation of steady production after bear fruit, we calculated the yield per unit area of jujube by referring to the calculation method of apple yield per unit area used by Wu and Wang [7] in the study of apple insurance rate calculation in Aksu region. In other words, the planting area of jujube trees in 1997 was taken as the planting area of actual output of jujube trees in 2002, and then it was calculated in turn with a period of 6 years.

3.2. Data Processing. Since the Copula function is used, the per unit area yield and price data are required to be stable. Therefore, SAS software is first used to conduct a stabilization test on the yield per unit area and price data of jujube trees, and it is found that these two sequences are not stable. The following is to consider the stabilization processing of the data.

For the stabilization of time series, there are both time domain analysis for the time trend of the series, such as

various linear or nonlinear trend models and frequency domain analysis for the fluctuation frequency of the stationary series at specific time points, such as Fourier transform. However, in actual production, the variation law of crop yield per unit area and price series is often more complex, which not only increases with the improvement of agricultural technology but also randomly fluctuates due to natural disasters and other conditions. Therefore, it is biased to adopt a simple time-domain analysis or frequency-domain analysis [20]. Wavelet analysis has the characteristics of multiresolution, which can decompose the signal into low frequency region and high frequency region. The analysis in time domain and frequency domain is more suitable for the stabilization of time series.

In this paper, wavelet multiresolution analysis is used to decompose the time series into multiple layers to separate the trend term and fluctuation term. Its essence is to decompose and reconstruct the nonstationary time series. The time series is decomposed into large-scale components (low-frequency signals, i.e., trend items) and small-scale components (high-frequency signals, i.e., wave items), and the superposition of the corresponding large-scale components and small-scale components is the original sequence, i.e.,

$$S = A_1 + D_1 = A_2 + D_1 + D_2 = A_3 + D_1 + D_2 + D_3 = \dots, \tag{1}$$

where S represents the original nonstationary time series, $A_i (i = 1, 2, \dots)$ represents the trend term of the nonstationary time series, and $D_j (j = 1, 2, \dots)$ represents the fluctuation term of the nonstationary time series.

Using the wavelet toolbox of MATLAB software, the tightly supported orthogonal wavelet SMY8 wavelet was selected to carry out wavelet multiresolution analysis on the yield per unit area of jujube and the price of jujube in Aksu region. It was found that the wave terms after two-layer wavelet decomposition and reconstruction all passed the ADF stabilization test. Considering the dimensional differences between the yield per unit area and the price, Z-score normalization was conducted for the stabilized sequence of fluctuation terms, and the data are shown in Table 1.

4. Establishment of Copula-Stochastic Optimization Model

4.1. *Fit Distribution Functions of Yield per Unit Area and Price of Jujube Tree.* EasyFit software was used to fit the distribution functions of the data series after the stabilization of yield per unit area and price of jujube in Aksu region, respectively. The results are shown in Table 2.

As can be seen from Table 2, both unit yield and price are subject to log-logistic (3P) function, and their distribution function is

$$F(y) = \left[1 + \left(\frac{\beta}{y - \gamma} \right)^\alpha \right]^{-1}, \quad y \geq \gamma, \tag{2}$$

and the probability density function is

$$f(y) = \frac{\alpha((y - \gamma)/\beta)^{\alpha-1}}{\beta[1 + ((y - \gamma)/\beta)^\alpha]^2}. \tag{3}$$

4.2. *Select the Optimal Copula Function.* Among the Gaussian Copula function, t-Copula function, Gumbel Copula function, Clayton Copula function, and Frank Copula function, the optimal Copula function was selected with the principle of minimum the square Euclidean distance from the empirical Copula function (as shown in Figure 1).

Empirical Copula [21]: let $(x_i, y_i) (i = 1, 2, \dots, n)$ be a sample taken from a 2-dimensional population (X, Y) . The empirical distribution function of X is $F_n(x)$, and the empirical distribution function of Y is $G_n(y)$, and the empirical Copula function is as follows:

$$\hat{C}_n(u, v) = \frac{1}{n} \sum_{i=1}^n I_{[F_n(x_i) \leq u]} I_{[G_n(y_i) \leq v]}, \quad u, v \in [0, 1], \tag{4}$$

where $I_{[\cdot]}$ is an indicator function,

$$I_{[F_n(x_i) \leq u]} = \begin{cases} 1, & F_n(x_i) \leq u, \\ 0, & F_n(x_i) > u, \end{cases} \quad \text{and}$$

$$I_{[G_n(y_i) \leq v]} = \begin{cases} 1, & G_n(y_i) \leq v, \\ 0, & G_n(y_i) > v. \end{cases}$$

MATLAB software was used to calculate the square Euclidean distances between the five Copula functions and the empirical Copula functions, respectively [21]. So, Frank Copula function was selected as the optimal Copula function adopting the principle of minimum the square Euclidean distance from the empirical Copula function. The results are shown in Table 3.

The distribution function of Frank Copula function is expressed as follows:

$$C_F^\alpha(u, v) = -\frac{1}{\alpha} \ln \left[1 + \frac{(e^{-\alpha u} - 1)(e^{-\alpha v} - 1)}{e^{-\alpha} - 1} \right], \tag{5}$$

and the probability density function is expressed as follows:

$$c_F^\alpha(u, v) = \frac{\alpha(1 - e^{-\alpha})e^{-\alpha(u+v)}}{[(1 - e^{-\alpha}) - (1 - e^{-\alpha u})(1 - e^{-\alpha v})]^2}. \tag{6}$$

Frank Copula function (Figure 2) has a symmetrical tail feature, which indicates that the yield per unit area and price of jujube trees are asymptotically independent. Kendall's rank correlation coefficient is -0.1626 , indicating that there is a very weak negative correlation between yield per unit area and price of jujube trees.

4.3. *Model Preparation.* Before establishing the stochastic optimization model, variables such as compensation amount, jujube farmers' income, and jujube farmers' risk should be further clarified.

TABLE 1: Z-score normalized data of fluctuation items in yield per unit area and price of jujube in Aksu region.

Time/year	2002	2003	2004	2005	2006	2007	2008	2009	2010
Yield per unit area	0.9209	-1.2248	-0.7132	-0.4427	2.96	-1.1104	-1.0053	-0.3387	0.8537
Price	-1.4635	2.3301	-0.9486	0.3199	-0.3625	0.2797	-0.2522	-0.9188	1.5111
Time/year	2011	2012	2013	2014	2015	2016	2017	2018	—
Yield per unit area	0.6656	-0.5131	0.1116	-0.3877	-0.2682	-0.0334	0.1674	0.3584	—
Price	-0.0232	0.1822	-1.1625	-0.3641	1.4938	-0.0033	-0.5163	-0.1018	—

TABLE 2: Distribution functions and parameters of jujube yield per unit area and price in Aksu region.

The data sequence	Distribution function	Parameters
Yield per unit area	Log-logistic	$\alpha = 3.40740, \beta = 1.60040, \gamma = -1.80370$
Price	Log-logistic	$\alpha = 4.48300, \beta = 2.28600, \gamma = -2.45590$

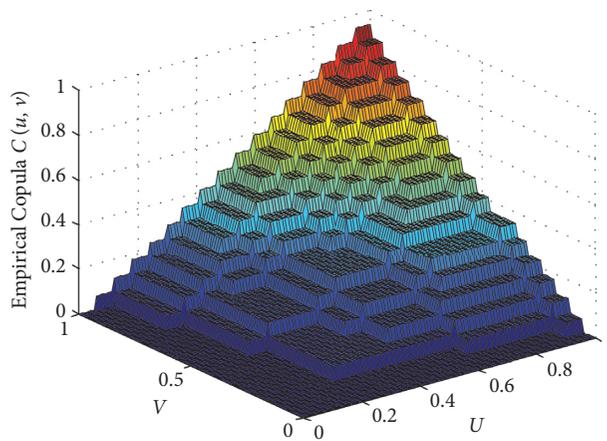


FIGURE 1: Empirical Copula function.

TABLE 3: Estimation results of the optimal Copula function.

Copula function	Parameter	Kendall rank correlation coefficient	Euclidean distance squared
Frank	-1.4956	-0.1626	0.0120
Gumbel	1.0000	$1.3575e - 06$	0.0125
Clayton	$1.4509e - 06$	$7.2543e - 07$	0.0125
Gaussian	-0.3024	-0.1955	0.0142
<i>t</i>	-0.3050	-0.1973	0.0143

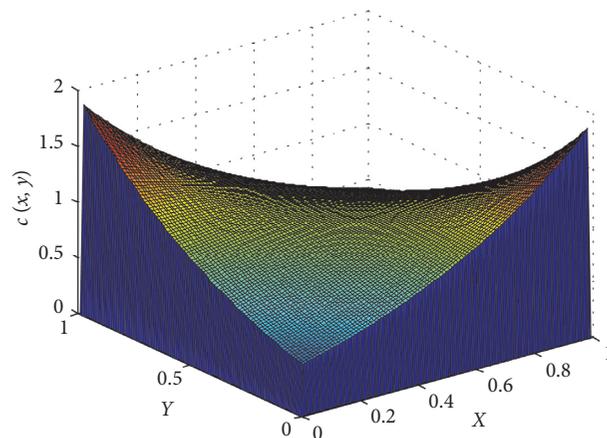


FIGURE 2: Probability density function of Frank Copula function.

4.3.1. *Compensation Amount.* After the jujube harvest period, when the actual income of jujube farmers (the insured) H is lower than the expected income agreed in the contract (insurance amount) \bar{H} due to the risk, the insurance company starts the claim settlement procedure, verify the cause of the loss and the extent of the loss, and pays the compensation.

Compensation amount is the cost that insurance company compensates to farmer: compensation amount $I = \text{insurance amount } \bar{H} - \text{jujube farmer's actual income } H$.

4.3.2. *Risk.* Risk is the core of this paper. How to define risk will directly affect the result of stochastic optimization.

The risk of jujube farmers is mainly reflected in the volatility of yield per unit area and price of jujube trees, which can be described by the variance of variables. The greater the variance is, the greater the risk is.

In this paper, the variance of date farmers' income from planting dates is selected to represent the risk of jujube farmers before insurance. Then,

$$S_0 = E(H^2) - [E(H)]^2. \tag{7}$$

Select the variance of the jujube farmer's income of planting jujube trees H plus the compensation amount I minus the insurance premium F (i.e., $H + I - F$) as the risk after insurance. Then,

$$S(x, y, Z, F) = E[(H + I - F)^2] - [E(H + I - F)]^2. \tag{8}$$

Substitute $F = ZM$ into the above equation, and the risks of jujube farmers after insurance $S(x, y, Z, F)$ are sorted out as $S(x, y, Z, M)$.

4.3.3. *Revenue.* Assuming that there is no moral hazard, the cost L of fertilizer, pesticide, labor, and other costs of planting one hectare of jujube is fixed. Let the probability density function of the yield per unit area of jujube tree x is $f_x(x)$, the probability density function of the price y is $f_y(y)$, and the joint probability density function of the yield per unit area and the price is $f(x, y)$. Select the mathematical expectation $E(H)$ of the jujube farmer's income H of planting

jujube trees minus the cost sL as the revenue $N_0(x, y)$ of jujube farmers noninsured, i.e.,

$$N_0(x, y) = E(H) - sL, \\ = \iint_{R^+} rp \times rq \times s \times f(x, y) dx dy - sL. \tag{9}$$

After the jujube farmers purchase insurance, the additional expenditure is the insurance premium F and the additional income is the compensation amount I . Thus, the revenue of the farmers $N(x, y)$ insured is obtained:

$$N(x, y) = N_0(x, y) + I - F. \tag{10}$$

4.4. Determine Constraint Conditions

- (1) Determination of decision variables

In this paper, select premium rate and insurance amount as decision variables

- (2) Determination of objective function

The target of insurance products is jujube farmers. It is assumed that there is no moral hazard. It is assumed that the cost of fertilizer, pesticide, labor, and other costs per hectare for each hectare are fixed cost L . Assume the income of the jujube farmer with the planting area s is H and the fixed cost is sL . Assume the expenditure is only the insurance premium. Then, the objective function of the optimization model is $S(x, y, Z, M)$ (i.e., the risk of jujube farmers insured).

- (3) Establishment of constraint conditions

First of all, the risk of jujube farmers insured should be lower than that of the noninsured, so as to establish constraint 1:

$$S(x, y, Z, M) < S_0(x, y). \tag{11}$$

Secondly, in order to avoid the speculative nature of insurance, the revenue of jujube farmers insured is limited, so that the revenue of jujube farmers insured is lower than that noninsured so as to establish constraint 2:

$$\iint_{\{(x,y)|x,y \in R^+, xy < Z\}} (xy - F + I) f(x, y) dx dy + \iint_{\{(x,y)|x,y \in R^+, xy < Z\}} (xy - F) f(x, y) dx dy \leq \iint_{\{(x,y)|x,y \in R^+\}} xy f(x, y) dx dy. \tag{12}$$

Thirdly, farmers' revenue should be improved as much as possible; on the other hand, in order to ensure the sustainability of insurance company operation, the earning of insurance company should

be positive and from 0+ tend to 0. In the optimization algorithm, in order to expand the feasible region of the algorithm, the earning interval of the insurance company is extended to $[-0.5, 0.5]$, which

TABLE 4: Premium rate and risk of jujube revenue insurance in Aksu region.

Guarantee level	100 (%)	95 (%)	90 (%)	85 (%)	80 (%)	75 (%)	70 (%)
Pure premium rate	11.33	10.06	8.81	7.61	6.43	5.31	4.24
Gross premium rate	16.42	14.58	12.77	11.03	9.32	7.69	6.14
Risk reduction ratio insured	47.03	41.75	36.45	31.21	26.08	21.15	16.51

Note. gross rate = net rate × (1 + safety factor) × (1 + operating expense factor) × (1 + predetermined savings rate), safety factor is 15%, operating expense factor is 20%, and predetermined savings rate is 5% [22].

is conducive to finding the optimal solution so as to establish constraint 3:

$$-0.5 \leq \iint_{\{(x,y)|x,y \in R^+, xy < Z\}} (F - I)f(x, y)dx dy + \iint_{\{(x,y)|x,y \in R^+, xy \geq Z\}} Ff(x, y)dx dy \leq 0.5. \tag{13}$$

Finally, the excessively high insurance amount will promote the emergence of moral hazard behavior of jujube farmers and also lead to the excessively high insurance premium, which will affect the insurance willingness of jujube farmers. Therefore, the insurance amount per hectare needs to be constrained.

According to relevant materials, the material cost of jujube tree planting in Aksu city is 18,000 Yuan per hectare, and the labor cost is about 12,000 Yuan per hectare. Therefore, the limited insurance amount is 18,000–30,000 Yuan per hectare, so as to establish constraint 4:

$$18000 \leq Z \leq 30000. \tag{14}$$

4.5. Solve the Stochastic Optimization Model

Step 1. Use MATLAB software, according to the probability density functions of yield per unit area and price. The random numbers of yield per unit area and price were generated by simple random sampling and selection sampling method, respectively.

Step 2. Use the random number obtained in Step 1 to solve the income of jujube.

Step 3. Call the “FMINCON” function library, set the initial value of insurance amount and premium rate as 22000 and 0.1, respectively, set the lower limit as 0 and the upper limit as 100000 and 0.5, and solve the model.

Step 4. Calculate the risk of noninsured and insured farmers’ by using the insurance amount and premium rate obtained.

Use MATLAB software to solve the stochastic optimization model and obtain that, at the 100% guarantee level, the insurance amount is 30000Yuan per hectare, the pure premium rate is 11.33%, the gross premium rate is 16.42%, and the premium is 4926 Yuan per hectare (according to the subsidy ratio of the current insurance award and subsidy

scheme, jujube farmers only need to bear 985.2 Yuan per hectare), and the risk of jujube farmers has decreased by 47.03% compared with that noninsured. The results are shown in Table 4.

5. Conclusions and Policy Recommendations

5.1. Conclusions

- (i) The stochastic optimization method can be used to determine the crop revenue insurance rate, which is more stable than such simulation methods as Monte Carlo simulation.
- (ii) The yield per unit area and the price of jujube in Aksu region are asymptotically independent, and there is a weak positive correlation.
- (iii) Revenue insurance plays a very important role in risk diversification of jujube farmers, and the risk after insurance is nearly 50% lower than that before insurance.
- (iv) Compared with the calculation result in this paper, “under the 80% guarantee level, the insurance amount is 24,000 Yuan per hectare, and the gross premium rate is 9.32%,” the current policy-based premium rate of 6% for fruit insurance is low. This may be because the current policy requires comprehensive consideration of the six main tree varieties of walnut, jujube, apricot, almond, apple, and grape, rather than just a single variety of jujube, so the insurance amount and premium formulated are not targeted enough for different trees and fruits [23].

5.2. Policy Recommendations

- (1) *Carry Out Jujube Revenue Insurance to Boost the Development of the Jujube Industry.* As the main producing area of jujube in Aksu, Xinjiang is vulnerable to natural disasters such as hail and wind damage. Market risks such as price factors cannot be ignored. In recent years, the price fluctuation of

Xinjiang jujube market is very violent, which seriously affects the healthy development of jujube industry and directly affects the economic income of jujube farmers. In order to prevent jujube farmers from going back to poverty again, carrying out jujube revenue insurance is necessary on the basis of the current policy-based insurance reward and subsidy policy of characteristic fruit industry, so as to boost the development of jujube industry and increase the income of jujube farmers in Xinjiang.

- (2) *Formulate Agricultural Insurance Policies in View of Different Fruit Trees.* Since 2010, Aksu has successively implemented the characteristic fruit industry insurance policies, which are unified insurance amount and unified premium rate for jujube, apple, and other major varieties. It is convenient to calculate and highly operable, but it is easy to promote moral hazard and adverse selection which is not conducive to the development of fruit industry [24]. Moreover, with the development of various fruit industries, the differences in cost and price are increasing. Therefore, it is necessary to formulate different agricultural insurance policies for different fruit varieties.
- (3) *Establish the Database of Fruit Industry.* The fruit industry is of great significance for Xinjiang farmers to get rid of poverty, but there is not too much data about the fruit industry. Considering the formulation of relevant policies such as agricultural insurance pricing, as well as the early warning research on industrial development and disaster early warning, it is suggested to establish a database for the fruit industry, which includes the disaster data of natural disasters, the product price, and planting cost data.
- (4) *The Government Needs to Continue to Provide Financial Subsidies for Agricultural Insurance and Support the Development of Agricultural Insurance such as Revenue Insurance.* The income of Xinjiang fruit growers is still lower in the whole country. Considering the insurance cost in fruit industry, insurance will increase the burden of fruit farmers, which may affect the fruit farmers to participate in the initiative to protect all kinds of risks. Therefore, finance of all levels of government may adopt the insurance premium award and subsidy policy implemented in the pilot at present and share the proportion of the insurance premium of fruit farmers [25].
- (5) *Increase Publicity to Enhance the Awareness of Risk and Insurance Participation of Fruit Farmers.* In addition to the pricing factors of agricultural insurance, such as insurance amount and premium, farmers' risk awareness and insurance participation consciousness also directly affect the implementation of agricultural insurance system and fundamentally determine whether the fruit insurance policy formulated can really play the role of guarantee.

Therefore, the government may organize professionals to popularize various professional knowledge and possible planting risks for fruit farmers and to increase the publicity of the fruit industry insurance, which can enhance the risk awareness and insurance participation awareness of fruit farmers and fully mobilize their enthusiasm for insurance participation, so that agricultural insurance can really play a role in protecting the fruit industry.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This study was funded by Southern Xinjiang Research Center of Agricultural Information, Institute of Agricultural Information, Chinese Academy of Agricultural Sciences (Study on Zoning of Planting Risk of Jujube in Southern Xinjiang, no. zx2015003), Tarim University-Chinese Academy of Agricultural Sciences Joint Fund Project (Study on Xinjiang Cotton Price Early Warning Model under the Background of Big Data, no. NJZX201601, and National Innovation and Entrepreneurship Program (Determination of Jujube Income Premium Rate Based on Copula and Stochastic Optimization Model, no. 202010058004).

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