Design of Wheat Drought Index Insurance in Shandong Province

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Abstract

Agro-meteorological index insurance can transfer the risks in the agricultural production, reduce the farmers' economic losses, and promote a sustainable development of agricultural production. However, traditional agricultural insurance with a single rate has the problems of the presence of adverse selection, the difficulty of determining premium rates and assessing the claims. As a new agricultural insurance product, weather index insurance, is based on the objective meteorological data, and it can determine the fee rates, make up for the damages, lower costs and make the claims more efficient .Thus, the paper establishes the wheat drought index which combines the precipitation anomaly percentage indicators with the growth characteristics of wheat in Shandong Province. Then, according to the meteorological data and wheat yields date of 17 cities of Shandong Province in 1981-2010, the paper analyzes the relationship between wheat drought and wheat production rate. Finally, this paper designs the wheat drought index insurance in Shandong Province which can provide a reference for the research and development of the policy agricultural insurance.

Keywords: *wheat; drought index insurance; design*

1. Introduction

As the second major wheat producing area, wheat production in Shandong Province plays a significant role in China's food security. But due to its special geographical condition, drought disasters occurred in Shandong with a high frequency, a wide range and a long duration, which caused a great deal of loss of the wheat production. Agricultural insurance can effectively transfer the risk of agricultural production, reduce the farmers' economic losses, and promote a sustainable development of agricultural production. Since 2004, the Central Government has been always highlighting the importance of developing policy agricultural insurance in the 1st Document. Especially in 2012, the Central Government has made an explicit proposal to expand the species and coverage of the agriculture insurance, and improve agricultural reinsurance system. Based on the meteorological data and production data, the research designs the wheat drought index insurance of Shandong Province, which can provide a basis for the government's disaster prevention and promote the application of agricultural insurance in China.

Agricultural insurance is an important means of risk management. It means the farmers pay insurance premiums to the insurance company, and then when they suffer an agriculture loss within the insurance range, they will get related compensation from the company Agricultural insurance is reflected in three forms: traditional agricultural insurance, crop area yield index insurance and weather index insurance. With a single rate traditional agricultural insurance has the problems of the presence of adverse selection, the difficulty of determining premium rate and assessing the claims. In the crop area yield index insurance, compensation can be available when the average yield of the region is less than the insured yield. As a new agricultural insurance product, weather index insurance takes the agricultural disaster as the subject and calculates the loss and claims based on the actual meteorological data, which solves the problems in traditional insurance and gets a wide range of application. Many foreign countries, including South Africa, Mexico have designed the rainfall index insurance to transfer the risks of floods and drought. Canada has used the weather index insurance to make up for the risk of loss caused by high temperature in planting corn and forage .South Africa has designed the apple frost weather index insurance in order to disperse the risk of the frost damage in apple growing. In China, Mao Yuding, Wu Lihong, *et al.*, (2007) selects the extreme minimum temperature as the meteorological indicators and designs the citrus frost damage index insurance contract of Zhejiang Province. Based on the Beta method, Wu Lihong, Lou Weiping, *et al.*, (2010) establishes a yield loss model for single cropping rice and designs a rice agricultural weather index insurance contract. By drawing on Malawi drought index insurance, Chen Xiaofeng, Huang Lu (2010) discusses the feasibility of sugarcane index insurance pilot in Guangxi Province and proposes the issues which the sugarcane index insurance should focus on. Liu Yingning, He Wenli, *et al.*, (2010) determine the frost damage risk period of apple florescence and calculate the agriculture insurance indexes of Shanxi apple flowering frost damage. Lou Weiping, Ji Zongwei, *et al.*, (2011) studies the relationship between Zhejiang Tea yield and frost damage and designs the tea frost weather index insurance to the township level. What's more, the agricultural weather index insurance has been used in China successfully. In 2008, Guoyuan Agricultural Insurance Company in Anhui Province designes the rice planting weather index insurance product which has been filed by the China Insurance Regulatory Commission.

The design and application of weather index insurance product should be different for different crop to different disaster. The researches about drought disasters in Shandong Province used to be focused on the causes and prevention. In view of the unique characteristics of the agricultural weather index insurance, the article designs the drought index insurance for wheat drought disasters in Shandong Province, which provides a scientific theory basis for the application of agricultural insurance in Shandong and even the whole country.

2. Data and methods

2.1 Data

The meteorological data used in the article comes from the Shandong Provincial Meteorological Bureau, including the daily precipitation of 17 Shandong Province's cities in 1981-2010 total 30 years. The wheat yield data comes from the Shandong Provincial Bureau of Statistics and the Shandong Province Statistical Yearbook, including the wheat acreage, total output data and wheat yield data of every city in 1981-2010 total 30 years. The wheat's growth period data mainly comes from various agro-meteorological stations in Shandong Province, including the start and end time of wheat planting, emergence, wintering, reviving, jointing, heading, and mature in 2001-2010years.

2.2 Methods and models

Based on the quantitative relationship between weather condition and crop production, the weather index insurance makes conditions of the damaging effects of weather on crop indexation. When the crop losses caused by the weather condition meet the insurance compensation standards, the insurance company will compensate the losses in accordance with the crop weather index. The weather insurance index contract mainly includes the type of contract, the contract period, the official weather station data, weather insurance index, insurance rates, trigger value and the amount of the compensation.

2.2.1 Wheat drought index: The drought index is a numerical expression of the drought. Domestic meteorological drought monitoring index are various, including the accumulated rainfall, the precipitation anomaly percentage, the Palmer Drought Index (PDSI), the soil moisture drought index, and the relative moisture index, *et al.*, Agricultural drought is mainly caused by the lack of precipitation .The calculation of the precipitation anomaly percentage indicators is simple and can directly reflects the precipitation caused by the crop drought which has been widely used in the field of meteorological drought and agricultural drought. Thus, the article establishes the wheat drought index which combines the precipitation anomaly percentage index with the growth and development characteristics of the wheat in Shandong Province.

The precipitation anomaly percentage refers to the negative percentage of the difference of the precipitations over a period of time and the average precipitations is over the same period accounted for the average precipitations. The expression is:

$$P_a = \frac{P-\overline{P}}{\overline{P}} \times 100\% \tag{1}$$

In the formula (1), P_a is the precipitation anomaly percentage, p is the precipitations over a period of time, $\overline{P}$ is the average precipitations over the same period and $P < \overline{P}$.

The drought index for the whole growth period of the wheat can be expressed as:

$$I_q = \frac{p_q - \overline{p_q}}{\overline{p_q}} \times 100\% \tag{2}$$

In the formula (2), I_q is the drought index of the wheat whole growth period, P_q is the actual precipitation, $\overline{P_q}$ is the average precipitations and $P_q < \overline{P_q}$.

In the crop drought risk, the whole growth period drought index is the dominant factor of the drought hazard. However, because of the uneven distribution of the precipitation, even if the whole growth period precipitation anomaly percentage is positive, if the crop water demand in the key period of water is shortage, it may still cause the crop cut in varying degrees. According to Doorenboos and Kassam (1979) showed in FAO's yield Response to Water, jointing stage is the water critical period of the winter wheat. So, the research introduces the drought index of the wheat jointing stage into the evaluation of the wheat drought in Shandong Province which making the evaluation of the crop drought index more scientific and reasonable. The drought index of the wheat jointing stage expressed as:

$$I_b = \frac{P_b - \overline{p_b}}{\overline{p_b}} \tag{3}$$

In the formula(3), I_b is the drought index of wheat jointing stage, P_b is the actual precipitation of the wheat jointing stage, $\overline{P_b}$ is the average precipitations of the wheat jointing stage, $P_b < \overline{P_b}$.

Thus, the wheat drought index can be expressed as:

$$I = \alpha_1 I_q + \alpha_2 I_b \tag{4}$$

In the formula(4), I is the wheat drought index, I_q is the drought index for the whole growth period, I_b represents the drought index of the jointing stage, α_1 and α_2 represents their corresponding weights.

2.2.2 Calculation of the wheat yield reduction rate: Crop yield is determined by the socio-economic factors and meteorological factors. Generally, the actual crop yield can be separated into three parts: the trend yield increased with the level of social production; the meteorological yield varied with the historical weather conditions; the random "noise" (typically can be ignored).In order to study the relationship between the wheat production and drought disasters in Shandong Province, the research should revise the yield data before the wheat production rate which is calculated excluding the socio-economic factors. The methods of estimating the crop trends yield can be divided into three categories: (1) the regression equation simulation method; (2) the moving average simulation method; (3) the linear moving average method. Based on the separation of the production data, the paper uses the linear moving average method to obtain each municipality's yield trend equations and simulate the trend of the production series. Among them:

$$Y = Y_t + Y_w \tag{5}$$

In the formula (5), Y is the actual crop yield; Y_t is the trend yield; Y_w is the meteorological yield.

The wheat yield reduction rate is the negative value of the relative meteorological yield. It can be calculated as:

$$x = \frac{(Y - Y_t)}{Y_t} \times 100\% \quad (Y < Y_t) \tag{6}$$

In the formula (6), x is the wheat yield reduction rate; Y is the actual crop yield; Y_t is the trend yield.

2.2.3 Ratemaking of the wheat drought index insurance: Assuming the actual crop yield is Y , the year trend yield is Y_t , the expectations for crop losses is $E(Loss)$ and the level of protection for the crop insurance is λ, then the crop insurance rate formula can be expressed as:

$$R = \frac{E(Loss)}{\lambda Y_t} \tag{7}$$

For the wheat policy agricultural insurance in Shandong Province, λ and Y_t take value 100%. Thus, the wheat drought insurance rate is the sum of the wheat yield reduction rate caused by drought disasters in different weather condition and its risk probabilities, which can be expressed as:

$$R_I = \frac{E(Loss)}{\lambda Y_t} = \sum_{i \le n} P_i \times x_i \tag{8}$$

In the formula (8), x_i is the different wheat yield reduction rate; P_i is the probability of different wheat yield reduction rate.

This article uses the Wheat Drought Index (I) to reflect the wheat drought weather conditions. As there is a one-to-one relationship between the wheat yield reduction and the drought disasters, the probability of different wheat yield reduction rate is the probability of the appropriate level of the drought disaster.

2.2.4 Calculation of the probability of the wheat drought risk: The traditional method of analyzing the agricultural drought risk is counting the frequency of different level of the drought risk, resulting in risk probability distribution. Using this method need enough sample, otherwise it will affect the accuracy of the result, even far from the actual situation. The Information Diffusion is a fuzzy mathematical approach which sets value to the samples and can turn the single-valued samples into set-valued samples, making the results more stable and accurate .And it is usually used for a variety of meteorological elements. Thus, based on the historical meteorological data, the research uses the normal diffusion model coming from the information diffusion theory to calculate the wheat drought risk probability.

Set up $I = \{I_1, I_2, \cdots I_m\}$ for the observations sample collection of the drought indicators; $U = \{u_1, u_2, \cdots u_n\}$ for the domain of the drought risk indicators.

In accordance with the following formula, the paper makes the information carried by each observed sample value I_j diffuse to all points of the indicators domain:

$$f_j(u_i) = \frac{1}{h\sqrt{2\pi}} e^{-\frac{(I_j - u_i)^2}{2h^2}} \quad (9)$$

In the formula (9), h known as the diffusion coefficient is determined by the size of the different samples, the maximum and minimum of the samples. Then, the corresponding membership function of the fuzzy subset can be expressed as:

$$\mu_{I_j}(u_i) = f_j(u_i) \Big/ \sum_{i=1}^{n} f_j(u_i) \quad (10)$$

Let

$$q(u_i) = \sum_{i=1}^{m} \mu_{I_j}(u_i) \quad (11)$$

$$P(u_i) = q(u_i) \Big/ \sum_{i=1}^{n} q(u_i) \quad (12)$$

Then, $P(u_i)$ is the frequency value when the sample falls at u_i, which can be regarded as the estimated value. The probability value which exceeds at u_i can be calculated as follows:

$$x(u_i) = \sum_{k=i}^{n} p(u_k) \quad (13)$$

In this article, $x(u_i)$ is the probability value when the wheat drought risk is greater than u_i. Then, the probability value of different wheat drought level can be calculated. Because of the one-to-one relationship between the wheat yield reduction and the drought disasters, the probability of different wheat yield reduction rate just means the probability of the drought disaster.

2.2.5 Calculation of insurance premiums: The wheat drought index insurance premium is the multiplier value of the pure premium rate and the amount of insurance, which is calculated as follows:

$$P_I = R_I \times Q \tag{14}$$

In the formula (14), R_I is the pure premium rate of the wheat drought index insurance; Q represents the amount of the insurance.

2.2.6 Calculation of the trigger value and the compensation value: According to the definition of weather index insurance and the contents of the insurance contract, the insured can request the appropriate compensation when the wheat suffers drought disasters and has a reduced. Thus, the rigger value needs to be calculated. The trigger value is the wheat drought index value when the wheat reduction is happened, which is less than the specified value (the wheat yield reduction rate is 0%).According to wheat policy insurance in Shandong Province, when the wheat yield reduction rate caused by drought is higher than 40%, the insurer can take the compensation in accordance with the terms of the responsibility of the insurance contract. So the article regards the wheat drought index value under the 40% wheat yield reduction rate as the trigger value. And the compensation value is the multiply value of the actual wheat yield reduction rate and the amount of insurance.

3. Design of the wheat drought index insurance in Shandong Province

3.1 Establishment of the wheat drought index in Shandong Province

Through the statistics of t the agricultural meteorological stations, the average growth cycle of Shandong wheat is October 4 to June 11 of the following year, which is the insurance period of the wheat drought index insurance in Shandong Province. And the subject matter of the insurance is the wheat yield loss due to drought disasters in the entire period. With the growth information of wheat in Shandong Province, the whole growth of the wheat in Shandong Province can be divided into six stages: the seedling stage, the wintering period, the reviving stage, the jointing stage, the heading stage and the mature stage. Based on the precipitation data and the wheat yield data, according to formula (1)-(6), the precipitation anomaly percentage at different growth stages and the wheat yield reduction rate can be obtained. Doing the correlation analysis between the precipitation anomaly percentage at different growth stages and wheat yield reduction rate over the years, we can get the following correlation coefficient value in Table 1.

Table 1. The correlation analysis between the precipitation anomaly percentage and wheat yield reduction rate in Shandong Province

Growth Stage of Wheat	Seeding Stage	Wintering Stage	Reviving Stage	Jointing Stage	Heading Stage	Mature Stage	Whole Stage
Start and end time	10.4-11.26	11.27-2.10	2.11-3.18	3.19-4.22	4.23-5.17	5.18-6.11	10.4-6.11
Correlation coefficient	0.1592	0.0857	0.1971	0.2382	0.0729	-0.1174	0.3683

Note: In Table 1 the correlation coefficient of wheat whole growth period is significant at the 1% significance level and the jointing stage data is significant at the 5% significance level.

According to the correlation coefficient in Table 1 and using normalization method to calculate, the weighting coefficients of the wheat drought index in the whole growth period is 0.61 and in the jointing stage is 0.39. Thus the wheat drought index in Shandong Province can be expressed as:

$$I = 0.61I_q + 0.39I_b \tag{15}$$

In the formula (15), I is the wheat drought index, I_q represents the drought index of the whole growth period and I_b represents the drought index of the wheat jointing stage.

3.2 The relation between the wheat drought index and the yield reduction rate

As the wheat yield reduction is not necessarily caused by meteorological disasters, the relationship between the wheat drought index and the wheat yield reduction rate is not absolutely correspondent. So, the data need to be processed before determining the relationship between them. Firstly, wheat drought disaster certainly occur which means the drought index must be less than 0; secondly, the wheat production should be in reduction which means the wheat relative meteorological yield must also be less than 0.But wheat yield reduction may be due to other disasters ,such as the frost, pests and diseases. Thus, combined with the drought disasters records in the Chinese meteorological disasters ceremony (Shandong volume), the research completed the data selection. Ultimately, according to the selected 232 sets of data, the article takes the regression analysis between the wheat drought index and the yield reduction rate, as showed in Figure 1.

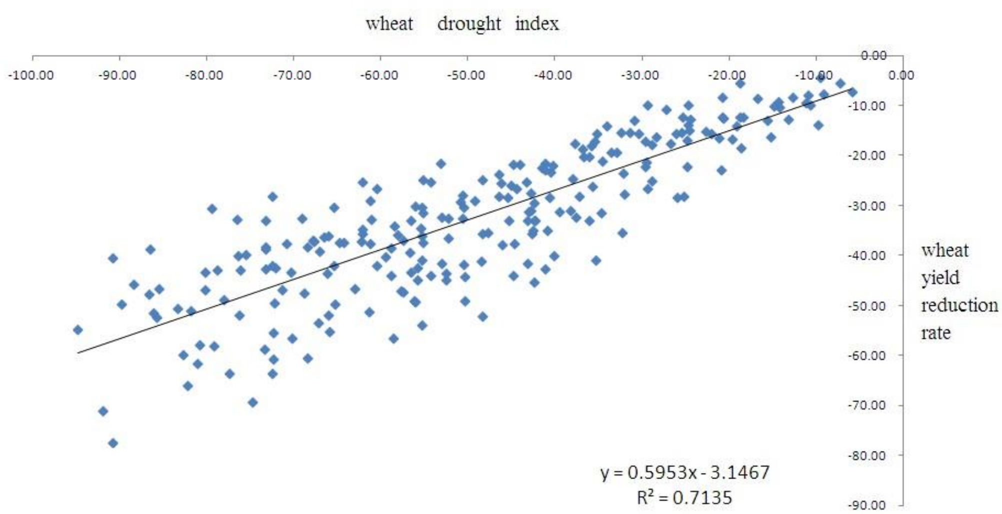

Figure 1. Regression relationship between wheat drought index and yield reduction rate

Seen from Figure 1, the regression equation of wheat drought index and the yield reduction rate in Shandong Province is:

$$x = 0.5953I\text{-}3.1467 \tag{16}$$

In the equation, x is the wheat yield reduction rate; I is the wheat drought index; R^2 is the regression equation's determination coefficient and its value is 0.7135, which better reflecting the relationship between the drought and the reduction of wheat.

In addition, by t-test on the coefficient of the regression equation, we can get $t = 23.93 > t_{\alpha/2} = 1.96$, that's the regression coefficient t value is greater than $t_{\alpha/2}$, indicating that the relationship between the wheat drought index and wheat yield reduction rate is positive linear significantly.

3.3 Determining the pure rate of wheat drought index insurance

According to 'The meteorological industry standard of wheat drought disaster grades', released by the China Meteorological Administration, the wheat yield reduction rate caused by drought disasters can be divided into four categories:0~10.0%,10.0~20.0%, 20.0~30.0%, >30%,which corresponding to light drought, moderate drought, severe drought and serious drought respectively. Combined with the regression equation of the wheat drought index and the yield reduction rate in Shandong Province, we can draw the different drought levels corresponding to the drought index values in Table 2.

Table 2. Wheat drought index grades in Shandong Province

Drought Types	Light Drought	Moderate Drought	Severe Drought	Serious Drought
Reduction Rate (%)	<10.0%	10.0~20.0	20.0~30.0	>30.0
Wheat Drought Index	-11.51~ 0	-28.31~ -11.51	-45.11~ -28.31	<-45.11

Adopting the information diffusion method to calculate the 17 cities' wheat drought index insurance rates, the formula is as follows:

$$\begin{aligned} R = {} & P(-11.51 \le I < 0) \times 5.0\% + P(-28.31 \le I < -11.51) \times 15\% \\ & + P(-45.11 \le I < -28.31) \times 25\% + P(I < -45.11) \times 65\% \end{aligned} \tag{17}$$

According to the wheat insurance policy of Shandong Province, the wheat policy insurance premium is 500 yuan / mu. The wheat drought index insurance premiums can be calculated as follows:

$$P = 500 \times R \tag{18}$$

In the formula (18), P is the wheat drought index insurance premium, R is the pure rate of the wheat drought index insurance. Taking the drought index data and the wheat yield reduction rate data into formula (17) and formula (18), the pure insurance rate and insurance premiums of the wheat drought index insurance can be obtained, as showed in Table3.

Table 3. 17 cities' pure rates and premiums of wheat drought index insurance in Shandong Province

City	Pure Insurance Rate (%)	Pure Insurance Premium (yuan)
Jinan	8.52	42.60
Qingdao	6.78	33.90
Zibo	9.65	48.25
Zaozhuang	6.22	31.10
Dongying	11.25	56.25

Yantai	7.25	36.25
Weifang	8.83	44.15
Jining	9.51	47.55
Taian	4.54	22.70
Weihai	3.21	16.05
Rizhao	2.43	12.15
Laiwu	8.66	43.30
Linyi	3.79	18.95
Dezhou	11.37	56.85
Liaocheng	10.69	53.45
Binzhou	10.14	50.70
Heze	7.84	39.20

From Table 3, we can find that the results of the pure rate of Shandong wheat drought index insurance shows a decreasing trend from the West to the East, which is consistent with the actual situation of Shandong Province. In the western, there is less precipitation leading to more drought disasters and higher insurance rate, contrary to the eastern. What's more, in Liaocheng, Binzhou, Weifang City and other major wheat producing areas, the wheat drought index insurance rate is higher, which is due to the major wheat producing areas are widely sown and suffer greater losses from the drought disasters. Thus, different areas should take different premium rate based on the size of meteorological disaster risk and losses when adopting the wheat agricultural insurance.. Insurance policies on wheat subsidies should also be carried out in accordance with the size of the pure insurance rate. The government should increase the investment and insurance subsides in the major wheat producing areas which is conductive to reduce the problem of adverse selection and arouse the enthusiasm of the farmers' participation in the insurance.

3.4 Determination of trigger values and compensation values

On the basis of the regression equation (Equation 16), when the wheat yield reduction rate reaches 40%, the corresponding drought index insurance trigger value would be -61.91, then the yield reduction rate can be obtained and the compensation can be calculated. For example, when the wheat drought index is -80, it would result in 50.77% of the wheat's yield reduction. As the wheat policy insurance premium is 500 yuan / mu, the insurance company should indemnify 253.85 yuan.

4. Conclusions and Discussion

On the basis of the area-yield index insurance and weather index insurance theory, the research designs the wheat drought index insurance in Shandong Province, including the duration of the insurance, the subject-matter insured, weather insurance index, trigger values, compensation values and insurance pure rate. The results of the pure rate of Shandong wheat drought index insurance shows a decreasing trend from the West to the East, which is consistent with the actual situation of Shandong Province. However, wheat yield reduction is the result of a variety of factors. When designing the drought index insurance, some other influencing factors including dry hot wind, frost as well as diseases and pests couldn't be completely removed. In addition, Shandong's terrain is complex and different regions face different wheat production environment. Due to lack of data ,the research only details to the municipal level, leading to the calculated results are not precise enough which should be further deepen in the future studies.

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