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Evaluating production risks for wheat producers in Beijing

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Abstract

Purpose – The purpose of this paper is to assess the production risk for winter wheat producers in Beijing, China, particularly in its 13 districts.

Design/methodology/approach – A parametric approach is used to model wheat-yield distribution for samples and the Kolmogorov-Smirnov test is used to choose the most appropriate yield distribution. Parameters of the special yield distribution are estimated through the maximum likelihood estimation approach.

Findings – The Burr distribution is found to be the most appropriate parametric distribution to model winter wheat-production risks for the districts of Beijing, except in the districts of Fengtai and Shunyi. Findings also show that the Johnson family distribution is the most appropriate model for these two districts (SB for the Fengtai District and SU for the Shunyi District). The wheat-production loss ratios of the Beijing districts are between 6 and 15 percent, which is considered medium range in most regions. The highest production risks are located in the Western regions of Beijing (Mentougou and Fengtai) while the lowest production risk is located in the Southeastern region of Beijing (Daxing District).

Originality/value – To generate an objective yield trend and an accurate production risk assessment, linear moving average, instead of linear (or quadratic) regression, is used in this paper.

Keywords Wheat, Risk assessment, Yield, China

Paper type Research paper

1. Introduction

Since the launch of agricultural insurance pilot programs in 2007, Beijing has made great progress in agricultural insurance during the past two years, such that farmers' participation rate has increased steadily and more than 30 percent of their agricultural products are now insured. Although the agricultural insurance program of Beijing is regarded as a module that is recommended for study, there are still many problems that need to be solved for the sustainable development of agricultural insurance. One of the most crucial problems in agricultural insurance is that the premium of an agricultural insurance contract is constant for the whole region of Beijing. This has proven to be irrational and can result in serious adverse selection and moral hazard problems (Knight and Coble, 1997; Rothschild and Stiglitz, 1976).

An actuarial premium for agricultural insurance should correspond to the risk level of the insured crop and should be subject to accurate evaluations of agricultural production risk. In China, however, few studies have been done on this issue, and premiums are calculated by empirical judgment, not by yield-risk level. Xing *et al.* (2008) evaluated and zoned the agricultural-production risks for Beijing. This assessment,

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however, assumed that crop-production risks follow a normal distribution, which has been proven in prior studies to be problematic (Lawas, 2005; Goodwin and Mahul, 2004; Glauber, 2004; Ramirez *et al.*, 2003). Aiming to provide more accurate suggestions for the sustainable development of agricultural insurance in Beijing, this paper takes winter wheat as an example and assesses wheat-production risk using a more appropriate parametric approach to set the accurate premium for Beijing's wheat-yield insurance.

2. Literature review

A survey of literature reveals that the concept of risk is defined and understood in different ways. Some scientists believe that risk is an uncertainty that affects an individual's welfare, and is often associated with adversity and loss, while others contend that risk is the possibility of adversity or loss (Harwood *et al.*, 1999). Sui (2004), in reviewing previous studies on risk, defines risk as the degree that actual revenues deviate from expected revenues due to uncertain events and the bounded rationality of people. According to her definition, wheat-production risk can be described as the degree that actual wheat yield deviates from its expected yield due to uncertain events and the bounded rationality of people. Generally, the process of assessing crop-yield risk and rating crop-insurance contracts can be done in three steps. The first step is to appropriate the yield trend and the second step is to model the yield risk. The third and final step is to evaluate the yield risk and ratemaking for crop insurance (Goodwin and Mahul, 2004).

2.1 Appropriating yield trend

For the adoption of improved technology and variety improvement, actual yield cannot reflect the true risk for the different time trend. It is necessary to break down crop yields into time-trend and variation components, which can demonstrate crop-production risk. Basically, the approaches of regression simulation (RS), moving averages (MA), and linear moving average (LMA), are available for "de-trending" yield data (Zhang, 1998). RS approaches, such as simple, quadratic, and cubic regression, were generally used to approximate the yield trend in previous studies (Lawas, 2005; Goodwin and Mahul, 2004; Xing, 2004; Deng *et al.*, 2006). However, RS approaches have considerable subjectivity in the selection of the time-trend model. The MA approach, on the other hand, could also lose data within the sample, while the LMA method[1] has the advantage of being more objective and retaining sample information without losses (Zhang, 1998). Thus, the LMA method was employed to approximate the yield trend in this paper.

After modeling the yield trend, the yield variation that can show the yield risk level can be obtained as follows:

$$Y_w = Y - Y_t \tag{1}$$

where Y denotes the actual yield, Y_t denotes the yield trend, and Y_w denotes the yield variation. Goodwin and Ker (1998) evaluated the heteroscedasticity of the de-trended yield data (Y_w) and found that the standard deviation of Y_w tended to be proportional to the average yield. Relative stochastic variation (RSV) is independent of time and space, and has more power to explain the impact of short-term factors (Deng *et al.*, 2002). Thus, this paper uses RSV to represent wheat-production risk:

$$\text{RSV} = \frac{Y_w}{Y_t} = \frac{Y - Y_t}{Y_t} \tag{2}$$

2.2 Modeling yield risk

The concept of yield risk modeling for purposes of assessing and rating crop-insurance contracts is fully analogous to modeling the probability distribution of yield risk for the crop in question (Goodwin and Mahul, 2004). Approaches to modeling yield densities and distributions can be undertaken either with parametric or non-parametric methods.

Although the parametric approach has the weakness that a prior parametric family must be assumed in advance, it has been widely used in previous studies. Turvey and Zhao (1999) and Sherrick *et al.* (2004) found that the appropriate yield distribution must be careful selected, and an incorrect yield-risk distribution will lead to a bias in the premium. Until now, a majority of studies have suggested that non-normal distributions, such as the beta, gamma, Weibull, Burr, log-normal, and inverse-hyperbolic sine distributions, can be used to model yield risk (Lawas, 2005; Goodwin and Mahul, 2004). The non-parametric approach does not require a prior assumption; however, it also has obvious shortcomings in its reliance on large samples and the potential difficulty of measuring rare events (Xing, 2004; Ramirez *et al.*, 2003). In general, a parametric approach is likely to be preferred if a prior distribution function is known, or the sample data set is small (less than 30-40 observations). A nonparametric approach, on the other hand, offers advantages in terms of its flexibility if a large amount of data are available (Goodwin and Mahul, 2004). For sample data spanning 28 years, the parametric approach is used in this paper.

2.3 Assessing yield risk and ratemaking for crop insurance

After modeling the yield risk, Deng *et al.* (2002) assessed the grain yield risk and calculated the probability of risk under different loss degrees using basic statistics formulae: $P(x \leq x1) = F(x1), P(x \geq x1) = 1 - F(x1)$, and $P(x1 \leq x \leq x2) = F(x2) - F(x1)$. This paper uses approaches similar to Deng *et al.*'s (2002) to quantify the wheat-production risk for the wheat producers of Beijing. Several studies also used risk modeling to set the premium for field-crop insurance, such as for wheat (Ke and Wang, 2002), corn, and soybeans (Sherrick *et al.*, 2004), and other field crops. A majority of studies put forward the thought that the pure premium of crop-insurance contracts should be equal to the exception of indemnity or yield loss (Lawas, 2005; Tuo, 1994). A basic formula can thus be shown as follows:

$$\begin{aligned} \text{Pure premium} &= \text{Expected insured} = E\max[\lambda u - y, 0] \\ &= \Pr\text{ob}[y < \lambda u][\lambda u - E(y | y < \lambda u)] \end{aligned} \quad (3)$$

where y is the actual yield, λ is the coverage level, and u is the expected insured yield. Since an RSV series was used to represent the wheat-yield risk, which is different from previous studies, we extended equation (3) to set the premium ratio for the wheat-yield insurance of Beijing in this paper (see Section 3 "Approaches" for details).

3. Approaches

Compared with previous studies, this paper assesses the wheat-yield risk and sets a premium for wheat-yield insurance, following the common process but using a different approach. This section focuses on an introduction to the approaches used in this study and explains how to select the most appropriate parametric model for yield-risk modeling.

In essence, LMA is a hybrid approach that combines simple linear regression and the MA approach. The first step of the LMA approach is to divide the sample series into sequence segments according to a given constant step (k). The first segment involves observations from 1 to k, the second segment involves observations from 2 to ($k+1$), and the process would not stop until the final segment is from $n-k+1$ to n where n means the number of observations. The step k is a crucial factor that affects effectiveness of LMA approach, and often set by simulation and comparison. We set $k = 11$ in this paper according to the disaster criteria of the Chinese Meteorological Administration (CMA, 2007).

The second step of LMA approach is to appropriate the yield trend in each segment using simple linear regression. Assume the linear regression model in segment i is:

$$y_i(t) = a_i + b_i t + \mu_i \tag{4}$$

where t means the rank code of each observation in a time series, and equals:

$$t = \begin{cases} 1, 2, 3, \ldots, k \quad \text{if } i = 1 \\ 2, 3, 4, \ldots, k+1 \quad \text{if } i = 2 \\ \vdots \\ n-k+1, n-k+2, n-k+3, \ldots, n \quad \text{if } i = n-k+1 \end{cases} \tag{5}$$

After modeling the yield trend in each segment, we can get more than one-fitted values for each observation. For example, there would be two fitted values for second observation because it was involved into the trend regression of Segments 1 and 2. Assume q is the number of the fitted values in each observation, and then it can be shown as:

$$q = \begin{cases} 1, 2, 3, \ldots, \underbrace{k, \ldots, k}_{n-2(k-1)}, \ldots 3, 2, 1 \quad \text{if } k \leq \frac{n}{2} \\ 1, 2, 3, \ldots, \underbrace{n-k+1, \ldots n-k+1}_{2k-n}, \ldots, 3, 2, 1 \quad \text{if } k > \frac{n}{2} \end{cases} \tag{6}$$

Finally, the yield-trend series can be estimated by dividing the sum of the fitted values by the number of fitted values in each observation (Zhang, 1998):

$$\bar{y}(t) = \frac{1}{q} \sum_{j=1}^{q} \hat{y}_j(t) \tag{7}$$

where $\bar{y}(t)$ denotes the yield trend of t th observation, and $\hat{y}_j(t)$ denotes the jth fitted value of tth observation.

After de-trending the time trend and obtaining the RSV series, the parametric approach was adopted to model the wheat-yield risk. The parametric approach involves using an observed series of yield observations to estimate specific parameters that describe a probability density or distribution function, so there is a need to select the most appropriate yield distribution for the available sample with the adoption of a parametric approach. In this paper, we first assumed that the wheat-yield risk in the Beijing region can be modeled by one of nine yield-distribution models that have advanced in previous studies (i.e. normal, lognormal, logistic, beta, Burr, gamma, Rayleigh, Weibul, and SU and SB of the Johnson family). Afterwards, a goodness-of-fit test was used to select the best model. Since the χ^2-test is not good for small samples, and the critical values of the Anderson-Darling test are available only for normal, lognormal, exponential, Weibull, extreme value type I, and logistic distributions (NIST/SEMATECH, 2003), the Kolmogorov-Smirnov (K-S) test was used to choose the most appropriate yield distribution from nine candidate yield distributions. Finally, the parameters of the yield-distribution model were estimated by the maximum likelihood estimation (MLE) approach.

As mentioned above, a revised approach to set the premium for crop insurance was used to determine the rate of the wheat-yield insurance. The actuarially fair premium of crop insurance contracts should be equal to the exception of indemnity or yield loss (Lawas, 2005; Tuo, 1994). Consider that insurers will pay indemnities (I) when the actual yield-loss ratio is higher than the guarantee level. In such a case, the premium (π) is:

$$\pi = E(I) = E[u * \text{price} * \max(Y_C - Y_R, 0)], \tag{8}$$

where u is the expected insured yield as above and the price is the unit price when losses are compensated. We assume that price = 1/kilogram. Y_C denotes the guarantee level of yield loss ratio, while Y_R represents the actual yield loss ratio. The yield loss ratio was defined as the rate of yield deviation against yield trend in this paper and can be show as $(y - y_t)/y_t$. The premium ratio of an insurance contract may then be computed as:

$$R = \frac{E[I]}{u} = \int_{-1}^{Y_C} (Y_C - Y_R) f(Y_R) \mathrm{d}Y_R \tag{9}$$

To simplify the calculations, the guarantee level of yield loss (Y_C) is assumed to be zero, which means that wheat-yield insurance contracts do not have deducible ratios and insurers will pay the indemnities if the actual yield loss falls beneath expected level.

4. Results

The municipality of Beijing, as the capital of China, is not a big agricultural producer. Crop producers are spread out in 13 of the 17 districts and counties in the region. The wheat producers under study in Beijing live in 11 districts (Changping, Chaoyang, Daxing, Fanshan, Fengtai, Haidian, Huairou, Miyun, Pinggu, Shunyi, and Tongzhou) and two counties (Mentougou and Yanqing). Actual production history yield data were used to assess the production risk for the wheat producers in Beijing. Wheat-yield data during the period 1978-2006 were obtained from the *Beijing Statistical Yearbook* and the Beijing Municipal Bureau of Agriculture.

As mentioned above, the LMA approach was used to approximate the wheat-yield trend for all samples. The wheat RSV series were then calculated using equations (1) and (2). From Table I, it can be seen that eight of the 13 districts of Beijing have negative skewness. In general, however, the skewness of the RSV series of wheat yield in Beijing region is positive (0.40), which means that the wheat-yield risk focuses on the left tail. Table I also shows that the wheat RSV series of the six districts (Changping, Fangshan, Fengtai, Haidian, Huairou, and Pinggu) cannot reject the null hypothesis of normal distribution with a 10 percent significant level, the RSV series of other seven counties

	Mean	Median	Max.	Min.	SD	Skewness	Kurtosis	JB-stat.	p-value
BJ	0.01	0.01	0.25	−0.21	0.08	0.40	6.37	14.53	0.00
Cping	0.00	0.00	0.31	−0.21	0.11	0.50	3.72	1.85	0.40
Cyang	0.00	0.00	0.17	−0.24	0.08	−0.62	5.24	7.91	0.02
Dxing	0.01	0.01	0.27	−0.17	0.08	0.96	5.79	13.87	0.00
Fshan	0.01	0.00	0.24	−0.18	0.08	0.38	4.55	3.61	0.16
Ftai	0.00	0.03	0.20	−0.26	0.13	−0.36	2.20	1.39	0.50
Hdian	0.01	0.02	0.31	−0.28	0.13	−0.13	3.29	0.19	0.91
Hrou	0.00	0.00	0.20	−0.28	0.10	−0.41	4.62	3.98	0.14
Mtgou	0.01	0.03	0.30	−0.46	0.16	−0.99	4.19	6.40	0.04
Myun	0.01	0.02	0.21	−0.34	0.10	−1.12	6.72	22.77	0.00
Pgu	0.01	0.01	0.24	−0.21	0.09	−0.25	3.94	1.36	0.51
Shyi	0.01	0.00	0.30	−0.20	0.08	0.99	7.74	31.84	0.00
Tzhou	0.01	0.00	0.37	−0.21	0.10	1.38	7.83	37.27	0.00
Yqing	0.01	0.00	0.22	−0.29	0.09	−0.50	5.89	11.27	0.00

Table I. Summary of RSV series of wheat yield in the Beijing region

and Beijing region, however, reject the null hypothesis at either 5 or 1 percent significance levels.

As mentioned above, we assume that the wheat-yield RSV series of the Beijing region and its 13 districts follow one of nine parametric distributions. The K-S test was used to choose the most appropriate distribution approach. Based on the K-S test results (the Appendix), it was found that the Johnson SU distribution[2] was the most appropriate method to model the wheat-yield risk for the Shunyi District. Johnson SB distribution, on the other hand, was the best one for the Fengtai District. For the 11 other districts or counties, the Burr distribution was the most fitting method. The MLE approach was used to estimate the parameters of the most appropriate distribution model for 14 samples. The most appropriate yield-distribution models and their parameter values for the Beijing region and its 13 districts are presented in Table II.

After modeling the yield risk for all samples, it was feasible to calculate the probability of different production risks. According to the criteria of disaster in the agricultural industry and Liu *et al.* (2006), we grouped the wheat-production risk into four classes, low, medium, high, and catastrophic, according to the loss ratio, which is defined as the ratio between the yield reductions[3] and the expected yield. The loss ratios (x) of low, medium, high, and catastrophic risks were defined as $0.05 < x \leq 0.15$, $0.15 < x \leq 0.25$, $0.25 < x \leq 0.35$, and $x > 0.35$, respectively. It can be seen from Table III that the probabilities of wheat-yield loss for all the samples, except in the Changping and Shunyi districts, are lower than 50 percent but higher than 40 percent; the wheat-loss probabilities in seven districts (Chaoyang, Fangshan, Fengtai, Haidian, Mentougou, Miyun, and Pinggu) are higher than the average loss probability of Beijing (47.66 percent). Column 7, however, shows that only three districts (Chaoyang, Daxing, and Tongzhou) have a lower mean yield risk than the average level of Beijing. Major wheat-yield risks of the Beijing region and its districts (or counties) are in the low-risk rank with the probability of occurrence falling between 15 and 26 percent. Table III also shows that wheat producers of the Mentougou District face the highest wheat-yield risk, followed by the farmers of Fengtai, Haidian, Changping, Pinggu, Huairou, Yanqing, Miyun, Fangshan, Shunyi, Chaoyang, Tongzhou, and Daxing.

	Appropriate yield distribution	Parameter values			
BJ	Johnson SU	$r = -0.16337$	$\delta = 1.4771$	$\lambda = 0.09065$	$\xi = -0.00643$
Cping	Burr (4p)	$k = 2.4386$	$a = 4.1875$	$b = 0.41505$	$r = -0.32293$
Cyang	Burr (4p)	$k = 1.1436$	$a = 66{,}179.7345$	$b = 2{,}743.0713$	$r = -2{,}743.0575$
Dxing	Burr (4p)	$k = 0.4607$	$a = 4{,}600{,}775.27$	$b = 118{,}932.406$	$r = -118{,}932.436$
Fshan	Burr (4p)	$k = 0.7791$	$a = 49{,}604{,}104.5$	$b = 1{,}936{,}507.94$	$r = -1{,}936{,}507.95$
Ftai	Johnson SB	$r = -0.5096$	$\delta = 0.9535$	$\lambda = 0.6335$	$\xi = -0.3837$
Hdian	Burr (4p)	$k = 1.6623$	$a = 27.6775$	$b = 2.2899$	$r = -2.2193$
Hrou	Burr (4p)	$k = 0.8729$	$a = 1{,}956{,}477.3$	$b = 90{,}996.3805$	$r = -90{,}996.3841$
Mtgou	Burr (4p)	$k = 11.8613$	$a = 54.1175$	$b = 6.9636$	$r = -6.5789$
Myun	Burr (4p)	$k = 1.1463$	$a = 19{,}578{,}960.2$	$b = 939{,}151.24$	$r = -939{,}151.219$
Pgu	Burr (4p)	$k = 1.3913$	$a = 348{,}690.16$	$b = 18{,}821.2687$	$r = -18{,}821.2342$
Shyi	Johnson SU	$r = -0.50475$	$\delta = 1.4677$	$\lambda = 0.08815$	$\xi = -0.03244$
Tzhou	Burr (4p)	$k = 0.64406$	$a = 43.7197$	$b = 1.5326$	$r = -1.5526$
Yqing	Burr (4p)	$k = 0.7660$	$a = 1{,}814.1644$	$b = 73.1563$	$r = -73.1683$

Notes: k and a are the shape parameters, b is the scale parameter, and r is the location parameter of the Burr distribution; r and δ are the shape parameters, λ is the scale parameter and ξ is the location parameter of the Johnson SU or SB distribution

Table II.
Appropriate distributions and parameter values of wheat-yield risk in the Beijing region

It is very meaningful to assess the crop-production risk and estimate the probability of varied yield loss. Based on Table III, we can identify the wheat-production risk level of the Beijing region clearly, including the average risk level and the spatial risk distribution, which will provide policy makers with valuable information necessary for crafting related policies. Based on the results of the risk analysis shown in Table III, we can also set accurate premium rates for wheat-yield insurance contracts, which is important in implementing a crop insurance program. Assuming that there are no

	Probability of loss (%)	Level of risk Low risk (%)	Medium risk (%)	High risk (%)	Catastrophe risk (%)	Mean (%)
BJ	47.66	17.51	1.95	0.28	0.07	2.25
Cping	51.86	26.24	5.80	0.17	0.00	3.84
Cyang	46.12	17.79	1.95	0.18	0.02	2.23
Dxing	48.33	15.59	0.43	0.01	0.00	1.65
Fshan	47.60	19.14	1.94	0.16	0.01	2.35
Ftai	46.00	18.83	11.49	3.80	0.06	5.35
Hdian	44.18	19.19	6.81	1.90	0.60	4.09
Hrou	47.24	20.37	3.17	0.38	0.05	2.81
Mtgou	41.44	15.56	7.96	3.69	2.80	5.38
Myun	43.50	17.80	2.75	0.35	0.05	2.46
Pgu	44.55	18.82	3.68	0.60	0.11	2.84
Shyi	50.95	19.61	1.53	0.15	0.03	2.32
Tzhou	48.06	18.97	1.27	0.05	0.00	2.17
Yqing	47.95	19.84	2.21	0.19	0.02	2.49

Notes: Probability of various yield-loss ratios; mean risk $= p(\text{low risk}) * 10\% + p(\text{mediumrisk}) * 20\% + p(\text{high risk}) * 30\% + p(\text{catastrophe risk}) * 40\%$

Table III.
Summary of wheat-production risk in the Beijing region and its 13 districts

deducible ratios in wheat-yield insurance contracts, the pure premiums of wheat-yield insurance in the Beijing region and its 13 districts (counties) are calculated according to equation (9) (Table IV).

5. Summary and conclusion

In this paper, crop-production risk is defined as the degree of difference between the actual crop yield and expected yield due to uncertain events and bounded rationality of people. We assessed the winter wheat-production risk of the Beijing region by modeling the probability distribution of wheat RSV series and evaluating the probability of various yield-loss ratios. Compared with previous studies, the LMA approach was used to obtain a more accurate wheat-yield trend series. K-S tests were used to select the best and most appropriate yield distributions to model the wheat-yield risk of the Beijing region and its 13 districts or counties. The Johnson SU distribution was found to be the most appropriate approach to model the wheat-yield risk for the Shunyi District while the Johnson SB distribution was the best one for the Fengtai District. For the 11 remaining districts of Beijing, the Burr distribution was the most fitting distribution.

Although the crop insurance program carried out in Beijing has only been in place only since 2007, there are still no accurate means to evaluate the exact level of crop-production risk. The results of this paper show that the probability of wheat-yield loss in the Beijing region is nearly 50 percent, but the wheat-production risk of Beijing is mild and concentrated between the ranges of 6 to 15 percent. The probability of occurrence varies from 15 to 26 percent. Meanwhile, 13 wheat-planting districts (and counties) in the Beijing region have different levels of yield risk. In general, Western areas of the Beijing region face higher wheat-yield risk compared to Eastern districts, while the lowest production risk is located in the Southeastern region of Beijing (Daxing District).

The accurate premiums of sound crop-insurance contracts should correspond to the yield risk level of liability covered by insurance contracts. The pure-premium results in Table IV and yield risk levels in Table III attest to this assertion. Table III shows that the wheat producers in the Mentougou District face the highest yield risk (5.35 percent). The pure-premium ratio (5.67 percent) of wheat-yield insurance in the Mentougou District was also the highest. In addition, according to the results shown in Table IV,

Regions	Pure-premium ratio (%)
BJ	2.57
Cping	3.98
Cyang	2.52
Dxing	2.03
Fshan	2.63
Ftai	4.95
Hdian	4.25
Hrou	3.04
Mtgou	5.67
Myun	2.69
Pgu	3.06
Shyi	2.64
Tzhou	2.46
Yqing	2.76

Table IV. Pure premiums of wheat yield insurance in the Beijing region we conclude that it is not viable to use a consistent premium ratio for wheat-yield insurance contracts in all the districts (and counties) of Beijing.

Notes

1. A detailed description of the LMA approach is listed in the approach section.
2. Mathematical equations for the Johnson test may be obtained from available at: www.mathwave.com/articles/johnson_sb_distribution.html
3. Yield reductions can take place when the actual yield is lower than the expected yield, and can be calculated using the equation $\text{Min}(0, \text{actual yield} - \text{expected yield})$.

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(The Appendix follows overleaf.)

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Appendix

Table AI.

Kolmogorov-Smirnov test of various yield distributions for the Beijing region and its 13 districts

	Stat.	Rank	Stat.	Rank	Stat.	Rank	Stat.	Rank	Stat.	Rank
	Beijing region		*Changping District*		*Chaoyang District*		*Daxing District*		*Fangshan District*	
Beta	0.21	6	0.09	4	0.16	7	0.20	4	0.12	6
Burr(4P)	0.17	2	0.08	1	0.13	1	0.16	1	0.08	1
Gamma(3P)	0.19	4	0.09	5	0.15	5	0.20	5	0.11	5
JohnsonSU	0.17	1	0.08	2	0.14	3	0.18	2	0.09	2
Logistic	0.19	3	0.09	6	0.13	2	0.21	7	0.10	3
Lognormal(3P)	0.20	5	0.09	3	0.14	4	0.19	3	0.11	4
Normal	0.21	7	0.10	7	0.15	6	0.23	8	0.12	7
Rayleigh(2P)	0.33	9	0.14	9	0.33	9	0.25	9	0.21	9
Weibull(3P)	0.21	8	0.10	8	0.17	8	0.21	6	0.13	8
	Fengtai District		*Haidian District*		*Huairou District*		*Mentougou District*		*Miyun District*	
Beta	0.16	7	0.13	5	0.19	7	0.12	4	0.15	3
Burr(4P)	0.11	3	0.10	1	0.15	1	0.11	1	0.13	1
Gamma(3P)	0.16	8	0.14	8	0.18	4	0.17	8	0.15	6
Johnson SU/SB	0.11	1	0.11	3	0.18	3	0.12	3	0.15	5
Logistic	0.15	6	0.11	2	0.17	2	0.14	5	0.15	4
Lognormal(3P)	0.15	5	0.13	7	0.19	6	0.15	6	0.15	7
Normal	0.15	4	0.13	6	0.19	5	0.16	7	0.14	2
Rayleigh(2P)	0.21	9	0.23	9	0.30	9	0.31	9	0.34	9
Weibull(3P)	0.11	2	0.13	4	0.20	8	0.11	2	0.15	8

(continued)

Table AI.

	Pinggu District		*Shunyi District*		*Tongzhou District*		*Yanqing District*	
Beta	0.138	4	0.17	4	0.21	5	0.21	6
Burr (4P)	0.109	1	0.15	2	0.16	1	0.19	1
Gamma (3P)	0.150	8	0.17	5	0.21	4	0.19	2
Johnson SU	0.120	2	0.15	1	0.21	3	0.22	8
Logistic	0.129	3	0.19	6	0.22	6	0.20	4
Lognormal (3P)	0.148	7	0.17	3	0.21	2	0.20	3
Normal	0.143	6	0.19	8	0.24	8	0.20	5
Rayleigh (2P)	0.251	9	0.28	9	0.27	9	0.32	9
Weibull (3P)	0.140	5	0.19	7	0.23	7	0.22	7

Kolmogorov-Smirnov test results for the most appropriate distribution of the Wheat RSV series in Beijing

	BJ	*Cping*	*Cyang*	*Dxing*	*Fshan*	*Ftai*	*Hdian*	*Hrou*	*Mtgou*	*Myun*	*Pgu*	*Shyi*	*Tzhou*	*Yqing*
Statistic	0.167	0.079	0.126	0.158	0.084	0.106	0.102	0.150	0.108	0.127	0.109	0.149	0.157	0.188
p-value	0.36	0.99	0.70	0.42	0.98	0.87	0.89	0.49	0.85	0.69	0.84	0.50	0.43	0.22