



A Study on the Insurance Rate of the Weather Index of Rapes in Jiangsu Province

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Abstract. Rapeseed, as one of the major oil crops in China, its production safety is of great significance to ensuring the national supply of grain and oil. As one of the top ten rapeseed production areas in Jiangsu Province, rapeseed production is vulnerable to natural disasters. Traditional agricultural insurance has problems such as rough rate determination and high moral hazard. Meteorological index insurance, based on objective meteorological data, can effectively reduce adverse selection and moral hazard. Based on the rapeseed yield and meteorological data of various cities in Jiangsu Province from 2001 to 2020, this paper uses the HP filtering method to separate the trend yield, constructs 12 meteorological indices such as precipitation, temperature and sunshine, and determines the pure rate through the parameter distribution fitting method and the non-parametric kernel density estimation method. Research shows that at a 100% coverage level, the net premium rate of rapeseed meteorological index insurance in Jiangsu Province ranges from 1.03% to 3.44%, and the net premium is between 9.01 and 30.19 yuan per mu. Finally, this paper conducts a comprehensive design of rapeseed meteorological index insurance from the perspectives of operation mechanism, dispersion of catastrophe risks, and multiple trigger conditions, and puts forward policy suggestions.

Keywords: Meteorological Index Insurance Rapeseed industry Rate determination; Jiangsu Province; Operation mechanism

1 Introduction

1.1 Research Background and Significance

China is a major agricultural country, and agriculture holds a strategic position in the national economy. Rapeseed, as a major oil crop, its safe production is closely related to the national economy and people's livelihood. Jiangsu Province is an important production area of rapeseed. In 2021, the output of rapeseed accounted for 57.64% of the total oilseed output of the province. However, rapeseed production is vulnerable to natural disasters and faces considerable risks. Since 2007, Jiangsu Province has launched a pilot program for policy-based rapeseed insurance. However, traditional materialized cost insurance has problems such as imprecise rates and low protection

levels. Meteorological index insurance is based on objective meteorological data and can effectively avoid moral hazard and improve insurance efficiency. This paper aims to study the rate determination of rapeseed meteorological index insurance in Jiangsu Province, providing a theoretical basis for the high-quality development of agricultural insurance.

1.2 Research Content and Methods

This paper adopts the rapeseed yield data and meteorological data of various cities in Jiangsu Province from 2001 to 2020, uses the HP filtering method to fit the trend yield, constructs the meteorological index system, determines the insurance rate through parametric and non-parametric methods, and conducts a comprehensive design of insurance products.

2 Literature Review

Scholars at home and abroad have conducted extensive and in-depth research on meteorological index insurance. In terms of advantage research, meteorological index insurance overcomes the shortcomings of traditional agricultural insurance in pricing and claims settlement, and is particularly suitable for the agricultural insurance field where the subject matter is scattered and the cost of surveying is high (Leblois, 2013) [1]. Wu et al. (2021) pointed out in their research on high-temperature heat damage insurance for rice in Jiangsu that index insurance based on objective meteorological elements has significant advantages in addressing adverse selection and moral hazard [2].

In terms of limited research, scholars have pointed out the multiple challenges faced by meteorological index insurance. Hellmuth et al. (2009) systematically analyzed the business difficulties existing in the promotion process of meteorological index insurance [3], including the difficulty in eliminating basis risks, low efficiency of departmental collaboration, and the shortage of professional talents. In the field of insurance design research, scholars at home and abroad have proposed a variety of innovative methods. Boyd et al. (2020) constructed a multivariate meteorological index based on three fundamental variables: rainfall, temperature, and sunshine duration through principal component analysis, effectively enhancing the accuracy of insurance products [4].

In terms of policy recommendation research, scholars have proposed measures to promote the development of meteorological index insurance from multiple perspectives. Wang Shihai et al. (2024) suggested that the government reduce the operating costs of index insurance by promoting data collection and sharing. Therefore, it is necessary to enhance the popularization and education of insurance knowledge [5].

Overall, the existing research provides important support for the theoretical development and practical application of meteorological index insurance. However, there is still room for deepening in aspects such as the construction of multi-factor meteorological indices and the design of regional differentiated products. Based on existing

research and in combination with the specific characteristics of rapeseed production in Jiangsu Province, this paper constructs a meteorological index system that includes multiple factors such as temperature, precipitation, and sunshine. Through comparative analysis of parametric and non-parametric methods, the scientificity and accuracy of rate determination are improved, providing a new research perspective and practical plan for the application of meteorological index insurance in the field of regional characteristic agricultural products.

3 Risk Analysis of Rapeseed Production in Jiangsu Province

3.1 Natural Disaster Risks

The natural disaster risks faced by rapeseed production in Jiangsu Province have distinct regional characteristics and seasonal patterns. As an East Asian monsoon climate zone, Jiangsu Province has a wide variety of meteorological disasters. Among them, the most prominent ones affecting rapeseed production include floods, low-temperature frost damage, and continuous overcast and rainy weather. According to the disaster statistics from 2010 to 2020, the average annual affected area of crops in Jiangsu Province reached 7.045 million mu, among which flood disasters accounted for more than 40%, and low-temperature frost damage accounted for about 4%. These disasters often occur in a single or combined form, causing differentiated impacts on different growth stages of rapeseed. Specifically, low-temperature frost damage mainly occurs during the seedling stage of rapeseed (from September 21st to January 29th of the following year), the bud and moss stage (from January 30th to March 15th), and the flowering stage (from March 16th to April 15th). When the temperature drops below 0°C, rapeseed will suffer from frost damage. Especially during the overwintering period, when the temperature is below -5°C, it will lead to a severe reduction in production. Flood disasters are mainly manifested as abnormally excessive rainfall during the growth period. In Jiangsu Province, the water requirement for rapeseed during the growth period is 300 to 500 millimeters. However, when the continuous rainfall exceeds this range, it will lead to water accumulation in the field, root deficiency, and subsequently cause root rot. Continuous overcast and rainy weather often forms a combined effect with insufficient sunlight, especially during the period from April 16th to May 15th. Such weather can significantly affect the photosynthesis and grain filling process of rapeseed. From the perspective of temporal and spatial distribution, the southern part of Jiangsu Province is more vulnerable to continuous overcast and rainy weather and flood disasters, while the northern part of Jiangsu Province faces a more severe threat of low-temperature frost damage. This regional difference makes the production risks of rapeseed in Jiangsu Province show obvious spatial differentiation characteristics, and also provides an objective basis for the determination of differentiated insurance rates [6].

3.2 Non-Natural Disaster Risks

In addition to natural disasters, rapeseed production in Jiangsu Province is also confronted with multiple non-natural disaster challenges. Although these risk factors do not directly manifest as natural phenomena, they also have a profound impact on the stable development of the rapeseed industry. First of all, the risk of market price fluctuations is particularly prominent. As a major agricultural product, the price of rapeseed is influenced by multiple factors such as the supply and demand relationship in domestic and international markets, policy regulation, and the prices of substitutes. Price data from 2003 to 2020 shows that the market price of rapeseed has experienced multiple significant fluctuations. This price uncertainty directly affects farmers' production decisions and income stability. Secondly, policy risks are also a factor that cannot be ignored. After the state abolished the temporary purchase and storage policy for rapeseed in 2015, the market price dropped significantly. Although Jiangsu Province promptly introduced a planting subsidy policy of 30 yuan per mu, the market adaptation period brought about by the policy adjustment still had an impact on rapeseed production [7]. In addition, adjustments and changes in agricultural insurance policies, farmland protection policies, environmental protection policies, etc., will all have a direct impact on the production scale and benefits of rapeseed. Technical risks are mainly manifested in aspects such as the promotion of new varieties, the application of cultivation techniques, and the prevention and control of pests and diseases. Although Jiangsu Province has a relatively high level of agricultural science and technology, there is still an imbalance among regions in the process of technology promotion. Some farmers have a relatively low acceptance of new varieties and new technologies, and it is difficult for them to change their traditional planting habits. To a certain extent, this has restricted the improvement of the production efficiency of rapeseed. Meanwhile, the control techniques for diseases and pests such as sclerotinia and downy mildew in rape also need to be constantly updated and upgraded to address new challenges such as the increased resistance of these diseases and pests. Social risks are mainly reflected in aspects such as the aging of the labor force and changes in the quality structure of agricultural practitioners. With the continuous outflow of young and middle-aged rural labor force, rapeseed production is facing problems of labor shortage and skills gap. This risk is particularly evident in production links such as rapeseed transplanting and harvesting, which require a large amount of labor.

4 Determination of the Pure Premium Rate for Rapeseed Meteorological Index Insurance in Jiangsu Province

4.1 Data Sources and Model Methods

1. Data sources: The rapeseed production data is from the "Jiangsu Statistical Yearbook", and the meteorological data is from the Jiangsu Meteorological Bureau.

2. Trend output fitting method: By comparing GM grey prediction, HP filtering method and quadratic exponential smoothing method, the HP filtering method was ultimately selected.

3. Meteorological index system: Establish 12 indices including precipitation, temperature, sunshine, and continuous overcast and rainy days, as shown in fig 1.

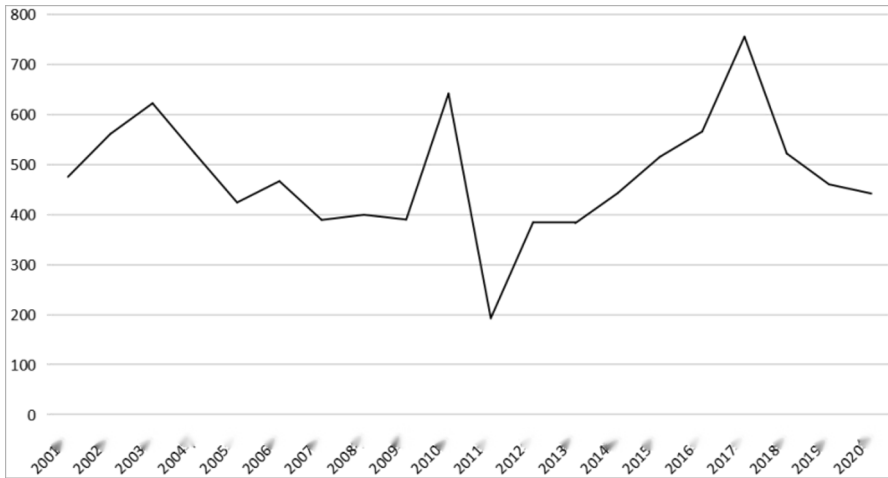


Fig. 1. Data analysis results

4.2 Determination of Trend Output and Reduction Rate

The trend yield is fitted by the HP filtering method, the relative meteorological yield is calculated, and the yield reduction rate is determined. The results show that the HP filtering method has the best fitting effect.

4.3 Regression Analysis of Meteorological Indices and Production Reduction Rate

Through Pearson correlation analysis, the main meteorological indices affecting the reduction of rapeseed production in each city were screened out, and a regression model was established.

4.4 Results of Pure Rate Determination

(1) Results of parameter distribution fitting method

The parameter distribution fitting method was adopted to determine the pure premium rate of rapeseed meteorological index insurance in Jiangsu Province. This method establishes a probability distribution model based on historical data and can accurately reflect the statistical characteristics of meteorological risks [8]. The study selected eight commonly used parameter distribution models such as the Gumbel Max distribution, Cauchy distribution, and Burr distribution. Distribution fitting was carried out through the EasyFit software, and the A-D test was used for goodness-of-order evaluation. The results show that there are significant differences in the optimal dis-

tribution of meteorological indices among different cities in Jiangsu Province. Among them, Changzhou, Yancheng, Suqian and Nantong are the most suitable for the Burr distribution, Xuzhou is the most suitable for the Johnson SB distribution, while Wuxi, Suzhou, Huai 'an and Lianyungang are more suitable for the Cauchy distribution [9].

In the process of determining the specific rate, first, based on the regression model of meteorological index and rapeseed yield reduction rate, the threshold range of meteorological index corresponding to different yield reduction rate levels is determined. Then, the occurrence probability of each threshold interval is calculated. Finally, the pure rate is obtained through weighted average. The calculation results show that at the 100% coverage level, the pure premium rate of rapeseed meteorological index insurance in various cities of Jiangsu Province ranges from 1.03% to 3.44%. Among them, the rate in Wuxi City was the highest (3.44%), reflecting that the meteorological risks faced by rapeseed production in this region were relatively prominent. The rate in Xuzhou City is the lowest (1.03%), indicating that the meteorological conditions in this area are relatively favorable for rapeseed production. This rate difference fully reflects the heterogeneity of rapeseed production risks in different regions of Jiangsu Province and also provides a scientific basis for the formulation of differentiated insurance rates.

(2) Results of non-parametric kernel density estimation methods

As a comparative study, this paper simultaneously adopts the non-parametric kernel density estimation method for rate determination. This method does not require the assumption of the overall distribution form in advance. It directly estimates the density of the sample data through the kernel function and has better adaptability. The study selected multiple kernel functions such as Uniform, Triangle, and Epanechnikov, and conducted estimations through Matlab software. The optimal window width determination method was adopted to ensure the estimation accuracy.

The nuclear density estimation results show that the pure premium rate of rapeseed meteorological index insurance in various cities of Jiangsu Province is distributed between 1.26% and 3.87%, which has certain differences from the results of the parametric method. Sensitivity analysis was conducted by setting different window width values, and it was found that the selection of window width had a significant impact on the estimation results. When the window width is too small, the density curve will show overfitting. When the window width is too large, some important information will be lost. After optimization and selection, the optimal window width values for each city were finally determined, such as 0.0245 for Changzhou, 0.018 for Nanjing, and 0.0148 for Suqian, etc.

(3) Comparative Analysis of the Two Methods

By comparing and analyzing the results of the parametric distribution fitting method and the non-parametric kernel density estimation method, it is found that the rates obtained by the two methods are relatively close in most cities, but there are significant differences in a few cities. Specifically, the rate differences between the two methods in Nanjing, Nantong, Wuxi and Suqian are relatively small (the difference rate is less than 5%), while the differences in Huai 'an, Xuzhou and Zhenjiang are relatively large (the difference rate exceeds 10%).

Further stability tests were conducted through analysis of variance. The rate variance obtained by the parametric method was 0.6047, and that by the non-parametric method

was 0.6777, indicating that the parametric distribution fitting method has better stability. This stability difference mainly stems from the fact that non-parametric methods are more sensitive to small sample data, while parametric methods can better smooth out random fluctuations through reasonable distribution assumptions. Therefore, in light of the actual situation and data characteristics of rapeseed production in Jiangsu Province, this study ultimately selects the parameter distribution fitting method as the main approach for rate determination.

From the perspective of practical application, the results of the parametric method are more in line with the risk characteristics of rape production in Jiangsu Province. For instance, the relatively high rate in Wuxi City coincides with the frequent occurrence of insufficient light disasters in the region, while the relatively low rate in Xuzhou City reflects the relatively superior meteorological conditions in the area. This practical risk pricing helps to enhance the scientificity and operability of insurance products, as shown in table 1.

Table 1. Net Premium Rate and Net Premium of Rapeseed Meteorological Index Insurance in Jiangsu Province

Region	Pure Rate	Pure Premium (CNY/mu)
Changzhou	2.76%	25.48
Huaian	1.46%	14.89
Lianyungang	1.88%	16.92
Nanjing	1.95%	17.78
Nantong	2.32%	28.03
Suzhou	3.01%	28.08
Wuxi	3.44%	30.19
Suqian	1.87%	16.79
Xuzhou	1.03%	9.01
Yancheng	1.24%	13.93
Zhenjiang	3.18%	30.58
Taizhou	2.03%	20.72

5 Comprehensive Design of Rapeseed Meteorological Index Insurance in Jiangsu Province

5.1 Operating Mechanism

The joint operation model of the government and insurance companies is adopted. The government provides subsidies, insurance companies operate independently, and farmers voluntarily take out insurance.

5.2 Catastrophe Risk Dispersion Mechanism

Establish a six-tier risk-bearing system, including farmers' self-retention, insurance companies, reinsurance companies, local and national catastrophe risk funds, and capital market investors.

5.3 Design of Trigger Conditions

In terms of the design of trigger conditions, this study proposes an innovative scheme that combines single trigger with multiple trigger conditions. A single trigger condition is based on the main meteorological index that affects local rapeseed production as the compensation standard. For instance, six cities including Lianyungang and Nanjing use the low-temperature frost damage index as the trigger condition, four cities including Changzhou and Nantong use the sunshine index as the trigger condition, Huai 'an uses the average temperature index as the trigger condition, and Xuzhou uses the continuous overcast and rainy index as the trigger condition. This trigger mechanism design based on dominant meteorological factors not only ensures the targeted nature of insurance products but also simplifies the claims operation process.

Taking the trigger conditions of low-temperature frost damage index as an example, this study innovatively combines the frost damage level with the duration and establishes a cumulative frost damage index model. Specifically, frost damage is classified into three levels: Level 1 frost damage (temperature -5 to 0°C) has a relatively minor impact, level 2 frost damage (-9 to 6°C) has a moderate impact, and level 3 frost damage (below -10°C) has a severe impact. When frost damage occurs multiple times during the growth period, the frost damage index is calculated by accumulating the frost damage levels. This design can more accurately reflect the cumulative effect of frost damage and improve the accuracy of insurance products.

Although a single trigger condition is mainly adopted at the present stage, this study proposes a forward-looking plan for the future development of multi-trigger condition insurance products. Multi-trigger condition design refers to the simultaneous consideration of the combined influence of two or more meteorological factors. This design can more comprehensively reflect the complexity of meteorological disasters and further reduce basis risks. For instance, continuous overcast and rainy disasters are often the result of the combined effect of excessive precipitation and insufficient sunshine. If only a single indicator such as precipitation or sunshine duration is used as a trigger condition, it may be impossible to accurately identify the occurrence of disasters. The dual-factor trigger conditions that can be explored in the future include but are not limited to: the combination of precipitation and sunshine duration, the combination of temperature and humidity, and the combination of key meteorological factors at different growth stages, etc. In addition, with the development of big data and artificial intelligence technologies, it is also possible to consider adopting machine learning methods to incorporate multiple meteorological factors into a unified model for training and automatically identify the optimal combination scheme of meteorological indices. This data-driven approach is expected to further enhance the accuracy and applicability of insurance products. On the implementation path with multiple trigger conditions, it

is recommended to adopt a phased advancement strategy. In the first stage, pilot projects can be carried out in regions with good meteorological data quality and solid research foundations. After accumulating experience, the projects can be gradually promoted. At the same time, it is necessary to establish a multi-departmental collaboration mechanism, integrate resources from meteorology, agriculture, insurance and other parties, and jointly promote the research and development and application of multi-factor meteorological index insurance products.

6 Conclusions and Policy Recommendations

6.1 Research Conclusion

Through an in-depth analysis of the meteorological index insurance for rapeseed in Jiangsu Province, this study has drawn the following important conclusions: Firstly, the meteorological risks faced by rapeseed production in Jiangsu Province show significant regional differences. This difference is not only reflected in the spatial distribution of risk types, but also in the regional characteristics of risk intensity. The southern part of Jiangsu Province is mainly threatened by continuous overcast and rainy days and floods, while the northern part of Jiangsu is more vulnerable to low-temperature frost damage. The objective existence of such regional differences determines that agricultural insurance products must adopt differentiated and refined rate determination strategies and cannot simply use a uniform insurance rate throughout the province.

Secondly, in terms of the comparison of rate determination methods, the parameter distribution fitting method demonstrates better applicability and stability. Through the comparative analysis of eight parameter distribution models and combined with the goodness evaluation of A-D test, it was found that there are differences in the optimal distribution models in different regions. Such differences precisely reflect the characteristic diversity of meteorological risks in various regions. The pure rate range obtained by the parametric method is 1.03%-3.44%. This result not only takes into account the risk probability but also reflects regional differences, and is highly scientific and reasonable. In contrast, although the non-parametric kernel density estimation method has the advantage of free distribution assumptions, it is more sensitive to small sample data and has relatively poor stability.

Thirdly, meteorological index insurance has significant advantages in reducing moral hazard and improving operational efficiency. Traditional agricultural insurance products require a large amount of manual investigation and loss assessment work during the claims process, which not only incurs high costs but also is prone to moral hazard. Meteorological index insurance makes claims decisions based on objective meteorological data. The claims process is transparent and efficient, which not only reduces the operating costs of insurance companies but also effectively curbs the opportunistic behavior of policyholders. This innovative insurance model provides new ideas and directions for the sustainable development of agricultural insurance.

6.2 Policy Recommendations

Based on the research conclusions, this paper puts forward the following policy suggestions: First, accelerate the development of meteorological index insurance for crops. It is suggested that Jiangsu Province, based on the existing research, select regions with distinct risk characteristics and a good data foundation to carry out the pilot work of meteorological index insurance. Focus on exploring the design of multi-factor meteorological indices and gradually establish an index insurance product system suitable for different crops and regions. At the same time, efforts should be made to enhance the publicity and promotion of meteorological index insurance, raise farmers' awareness and acceptance, and lay a solid foundation for its comprehensive promotion.

Second, establish a complete agricultural risk management system. Meteorological index insurance is only one component of the agricultural risk management system and needs to be coordinated with other risk management tools. It is suggested that a complete risk management chain be established, including disaster early warning, disaster prevention and mitigation, risk transfer, post-disaster compensation and other links. In particular, efforts should be made to enhance the capacity for monitoring and early warning of meteorological disasters, improve the accuracy and timeliness of disaster forecasts, and provide reliable basis for risk management decisions.

Fourth, improve the construction of basic databases. In view of the current problems of low quality and insufficient continuity of agricultural data, it is suggested to establish a long-term and stable data collection and update mechanism. In particular, efforts should be made to enhance the collation and digitization of historical disaster data and establish a complete disaster case database. In addition, attention should be paid to data quality control, and a data quality assessment and correction mechanism should be established to ensure the accuracy and reliability of the data. Through the construction of a complete basic database, it provides strong support for the precise design and scientific pricing of meteorological index insurance products.

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