Optimization of Weather Index Insurance for Rice Cultivation Based on Relaxed Lasso-blockchain Hybrid Technology: A Case Study in Anhui Province

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Abstract

Taking Anhui Province as a case study, this research addresses the pain points of traditional weather index insurance for rice cultivation. It proposes applying the Lasso algorithm to screen multiple weather factors for optimizing the payout index. Using June wind speed as the core quantitative factor, a risk assessment framework based on historical meteorological and yield data is constructed. Simultaneously, it innovatively integrates blockchain technology throughout the insurance lifecycle, establishing a decentralized system for policy purchase, underwriting, claims processing, and data sharing. Leveraging smart contracts enables automatic claims settlement triggered by meteorological data, significantly reducing underwriting and claims assessment costs while enhancing transparency and mitigating moral hazard and adverse selection. To further promote market adoption, the study designs incentive mechanisms and referral programs to improve information disclosure and user engagement. Overall, this innovation enriches the agricultural insurance system both theoretically and practically, substantially reducing information asymmetry and basis risk, and holds potential to stabilize farmer incomes and foster the healthy development of the insurance industry.

Keywords

Weather index insurance, Blockchain, Relaxed Lasso, Agricultural risk management

Introduction

As the primary sector, agriculture must accelerate the cultivation of new productive forces. This is both crucial for responding to international competition and an essential requirement for achieving high-quality development [1]. Agricultural insurance, as a vital tool for agricultural risk management, plays an irreplaceable role in safeguarding farmers' incomes and ensuring stable agricultural production [2]. Rice, as a primary staple crop, is susceptible to various weather risks during cultivation. Traditional agricultural insurance and existing weather index insurance for rice cultivation have limitations, while advancements in blockchain and machine learning technologies offer new approaches to address these constraints [3]. This study builds upon the original (Least Absolute Shrinkage and Selection Operator) Lasso algorithm by developing a Relaxed Lasso algorithm, exploring weather index insurance for rice cultivation through an innovative approach. Theoretically, it enriches the theoretical framework of agricultural insurance; practically, it reduces insurance risks, safeguards farmers' income, and promotes the healthy development of the agricultural insurance industry.

Current status and innovation pathways for weather index insurance in rice cultivation

Core concepts and practical limitations of weather index insurance for rice cultivation

(1) Defining fundamental concepts

Index insurance requires the prior design of a compensation mechanism. When a specific parameter reaches the predetermined trigger level, the policyholder may submit a claim request to the insurance company [4,5]. In this paper, the index refers to intensity indicators for certain disasters.

Weather index insurance for rice cultivation is an agricultural insurance product triggered by objective meteorological indicators closely linked to rice growth,

such as cumulative rainfall, extreme high/low temperatures, typhoons, flood/drought indices, etc. Threshold values and payout curves for each growth stage are pre-set based on long-term historical meteorological and yield data. When observed values reach or exceed thresholds, payouts are rapidly disbursed according to predefined formulas without requiring verification of actual losses in individual fields.

(2) Advantages and pain points of existing models

a) Core advantages

Weather index insurance for rice cultivation offers advantages including objectivity, transparency, rapid settlement, and reduced moral hazard and adverse selection [6]. It can leverage meteorological stations and satellite remote sensing to broaden coverage. Its primary objective is to mitigate yield or income fluctuations caused by weather anomalies, serving as an effective supplement to traditional actual-loss agricultural insurance. This helps farmers stabilize operations and access financing.

Insurance reduces disaster losses in agricultural production by providing timely, effective, and reasonable compensation to affected farmers. With relatively small premiums, farmers gain substantial compensation, securing funds to replenish production inputs for agricultural recovery [7]. Simultaneously, insurance alleviates the burden of fiscal disaster relief. When agricultural production suffers general disaster losses, insurance institutions can provide compensation, reducing the need for government relief funds and thereby decreasing government fiscal expenditures.

b) Addressing key pain points

Information asymmetry: Agricultural index insurance suffers from low information transparency, with unclear data sources, unclear compensation standards, and unclear calculation processes. Policyholders also face adverse selection issues during the underwriting process [8]. In drier years, rice farmers may anticipate reduced yields due to drought based on their experience and weather station forecasts, increasing their motivation to purchase weather index insurance for rice cultivation. Conversely, in years with unpredictable weather, farmers may purchase this insurance infrequently due to trust concerns. Consequently, policyholders for this insurance are predominantly

high-risk users, posing a significant risk of financial loss for insurance companies.

High underwriting and verification costs: During underwriting, existing weather index insurance for rice requires agents to promote the product, coordinate with local governments or village officials, and input data into systems after farmers complete applications and household lists. Claims verification demands not only farmers submitting documentation but also significant resources for on-site disaster assessments - including measuring affected land areas and crop types. This results in substantial underwriting and verification workloads, inevitably leading to higher costs [9,10].

Basis risk and delayed payouts: Claim standards for rice weather index insurance are typically based on indices like temperature and rainfall [11]. However, these indices often fail to accurately measure the extent of farmers' losses, resulting in payouts that frequently fall short of compensating for their actual losses. Furthermore, the entire process - from detecting and obtaining the indices employed for claim assessment to determining eligibility on the basis of these indices - requires a substantial amount of time. The actual payout procedure also involves considerable time consumption. This delay prevents the insurance product from providing timely and effective protection for farmers' interests.

Challenges in promotion: Farmers have limited access to insurance information, and weather index insurance offers narrow coverage, making it difficult to meet their personalized insurance needs. The existence of "basis risk" makes it difficult for farmers to accept contractual terms. When insurance payouts fail to fully compensate for actual losses, farmers perceive the product as unreliable and unfair. Furthermore, some farmers, based on the above circumstances, believe their experience can prevent or significantly reduce losses from weather risks, developing a complacent mindset that discourages them from purchasing agricultural index insurance.

Innovation in weather index insurance for rice cultivation

Addressing the key pain points of existing rice weather index insurance, we employ blockchain technology and the Relaxed Lasso algorithm to redesign and enhance current rice weather index insurance products, creating

an innovative agricultural insurance solution.

(1) Blockchain technology reconstructs the entire insurance process

Core technical features:

Blockchain technology is a decentralized system based on distributed ledgers, featuring core characteristics including decentralization, immutability, transparency and traceability, and smart contracts. Decentralization distributes data storage across nodes, preventing data loss from single-point failures; immutability employs cryptographic algorithms to encrypt data, requiring majority node validation for each transaction entry to ensure authenticity. Transparency and traceability enable all nodes to view ledger data, with modification records fully traceable throughout the process. Smart contracts are computer programs that execute automatically based on predefined rules, enabling transaction process automation [12].

Intelligent algorithm combined with information technology has been widely applied in industrial process optimization and supply chain network reconstruction, and its technical fusion logic provides a feasible reference for the combination of algorithm and blockchain in agricultural insurance optimization [13].

Penetration pathways in insurance scenarios:

In the insurance sector, blockchain technology effectively addresses information asymmetry: First, in policy management, electronic policies recorded on the blockchain become tamper-proof throughout their lifecycle, preventing claims disputes caused by altered policy information. Second, in data sharing, multiple parties - including insurance companies, meteorological departments, and farmers - can achieve real-time data exchange via consortium blockchains, reducing data silos. Third, in claims processing, smart contracts can automatically trigger payouts based on predefined weather indices without human intervention, shortening claim cycles.

Promoting transparency in agricultural insurance products is a pressing issue requiring immediate attention. The increasingly prominent blockchain technology in recent years offers an ideal solution to this challenge. The Figure 1 illustrates the architecture of "blockchain + weather Index" insurance.
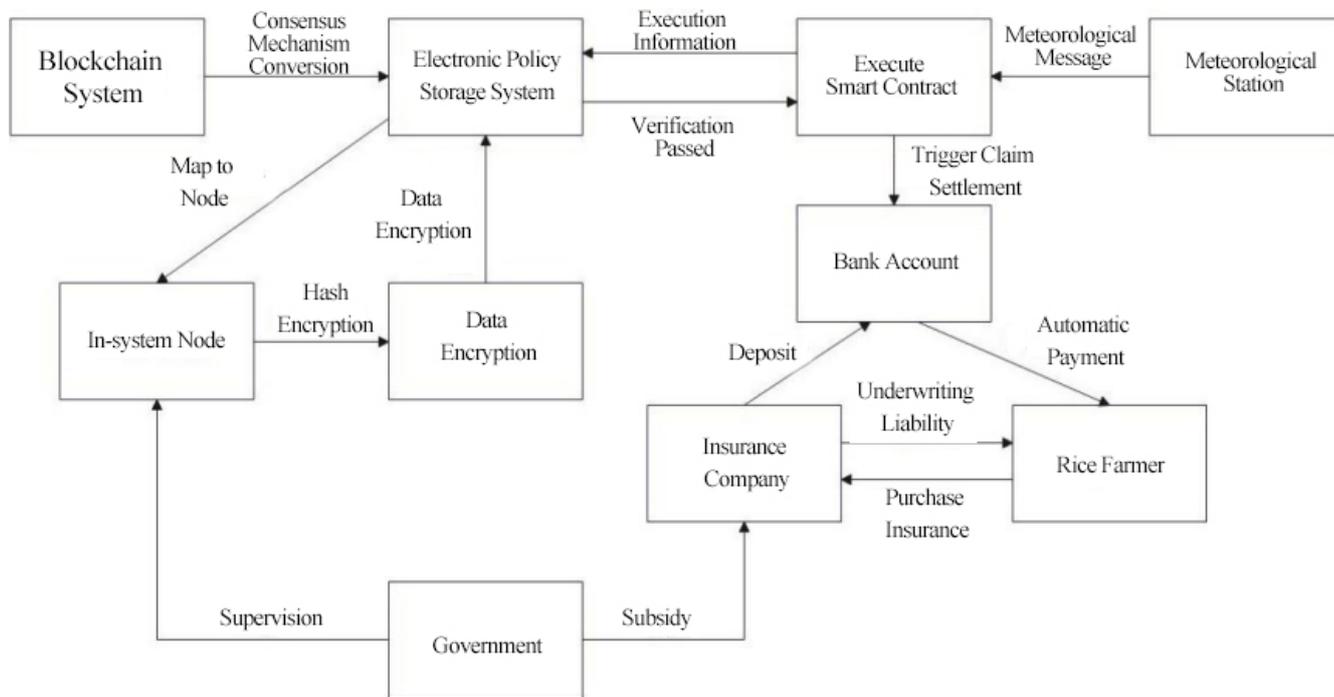

Figure 1. "Blockchain + weather index" insurance architecture.

Blockchain technology has comprehensively transformed specific operational processes into traditional agricultural insurance products, including farmer enrollment, insurer underwriting, policy information verification and entry systems, farmer claims applications, and insurer claims verification.

Additionally, beyond the aspects embodied in the insurance framework, blockchain technology introduces a key feature absent from traditional agricultural insurance product structures - a reward mechanism.

First, the target function of the standard Lasso (L1 regularization) is defined as follows:

$$min_{\beta_0,\beta \epsilon R^P} \frac{1}{n}\sum_{i=1}^{n}(y_i - \beta_0 - x_i^T\beta)^2 + \lambda \sum_{j=1}^{p}|\beta_j| \qquad (1)$$

where y_i denotes the response variable (e.g., insurance claim amount related to June wind speed fluctuations), x_i is the vector of explanatory variables for the i-th sample, β_0 is the intercept term, $\beta=(\beta_1, \beta_2, ...,\beta p)^T$ is the coefficient vector of explanatory variables, n is the sample size, p is the number of explanatory variables, and λ is the regularization parameter that controls the strength of L1 penalty.

(2) Relaxed Lasso algorithm optimizes payout index

To clarify the methodological foundation of the risk assessment algorithm proposed in this paper, the target function of the Relaxed Lasso used is explicitly defined herein, and its differences from the standard Lasso are elaborated, along with a theoretical proof of its advantage in reducing base risk.

Traditional weather index insurance for rice typically relies on a limited set of indices, often based solely on two weather factors: temperature and precipitation. This approach prevents insurers from accurately quantifying farmers' losses during claims processing, thereby hindering the determination of reasonable compensation. However, the Lasso algorithm can identify the most influential weather factors affecting rice yield reduction from a wide range of variables. By incorporating these factors into the existing index, the insurance index can be optimized, thereby reducing basis risk. Intelligent algorithm has become a core technical tool for optimizing industrial production processes and screening key evaluation indicators, and its application in process industry has verified the effectiveness of algorithm-driven quantitative optimization [14].

This section uses rice production data from selected regions in Anhui Province between 2000 and 2020 as an example. Relevant weather indicator data were collected and organized, including rice yield, monthly average temperature, monthly average precipitation, monthly average relative humidity, total sunshine duration, and monthly average wind speed for each month from April to June. By applying the Lasso dimensionality reduction model, correlated dependent weather factors were identified, as shown in Table 1.

Correlation between weather indicators and rice yield: The Relaxed Lasso algorithm was used to analyze the correlation between the weather indicators listed in Table 1 and rice yield, and the results showed that different weather factors have distinct effects on rice yield. Specifically, April and May average temperatures (T4, T5) are positively correlated with rice yield within the suitable growth range (15-30℃), as appropriate temperature promotes rice tillering and leaf development; excessive or insufficient temperatures will inhibit yield. April and May average precipitation (P4, P5) show a positive correlation with yield in moderate ranges, while excessive precipitation leads to waterlogging, reducing soil oxygen content and affecting root growth, thus negatively impacting yield. Monthly average relative humidity (M4, M5, M6) and total sunshine duration (S4, S5, S6) are positively correlated with yield - appropriate humidity reduces water stress, and sufficient sunshine ensures photosynthesis efficiency. The light-to-temperature ratio (G4, G5, G6) is positively correlated with yield, as a reasonable ratio optimizes the coordination of photosynthesis and respiration. Among all factors, June wind speed (F6) is the most prominent factor negatively correlated with rice yield (i.e., positively correlated with yield reduction), which is consistent with the algorithm analysis results.

Based on the data in Table 1, analysis using the Relaxed Lasso algorithm reveals that the June wind speed index is positively correlated with the reduction in rice yield. That is, a higher wind speed index exerts a stronger inhibitory effect on rice yield. Mechanism of June Wind Speed index affecting rice yield: June is a critical growth period for rice in Anhui Province, corresponding to the jointing and booting stage - this is the key period for rice panicle differentiation, spikelet formation, and grain filling, during which the rice plant is relatively fragile and sensitive to external disturbances. When the average June wind speed is too high (exceeding 3 m/s for a long time), it will cause multiple adverse effects on rice growth:

First, strong winds will damage rice stems and leaves, break or lodging the plants, leading to reduced photosynthetic area and inability to accumulate sufficient nutrients. Second, strong winds will accelerate water evaporation on the leaf surface,

causing water stress in rice plants, affecting the absorption and transportation of water and nutrients, and inhibiting panicle development. Third, excessive wind speed will disrupt the pollination process of rice, reducing the seed setting rate and grain plumpness. Fourth, long-term strong winds will increase the incidence of rice diseases and insect pests (such as rice blast and stem borers), further exacerbating yield reduction. Therefore, the fluctuation of June wind speed directly affects the stability of rice yield, and its high fluctuation characteristics make it an important indicator reflecting rice yield risk.

Table 1. Weather factors.

Representative symbol	Weather factor	Representative symbol	Weather factor
T4	April average temperature	M5	May average humidity
P4	April average precipitation	F5	May average wind speed
S4	April average sunshine duration	G5	May average light-to-temperature ratio
M4	April Average Humidity	T6	June average temperature
F4	April average wind speed	P6	June average precipitation
G4	April average light-to-temperature ratio	S6	June average sunshine duration
T5	May average temperature	M6	June Average Humidity
P5	May average precipitation	F6	June average wind speed
S5	May average sunshine duration	G6	Average light-to-temperature ratio in June

To visually illustrate the historical variation of this core factor, this paper presents a detailed statistical table of June wind speed fluctuations from 2000 to 2020 (see Figure 2). This figure clearly reflects the temporal and regional fluctuation patterns of June wind speeds over the past two decades, providing both solid temporal data support for the correlation conclusions derived from the Lasso algorithm and a critical historical reference for subsequent in-depth quantitative studies on rice yield risks.

Historical data in Figure 2 clearly indicates that average June wind speeds exhibit notable significant fluctuations. Following professional insurable risk assessment, these fluctuations fully meet core strict requirements for risk events in formal insurance operations and qualify as a valid core index for claims settlement.
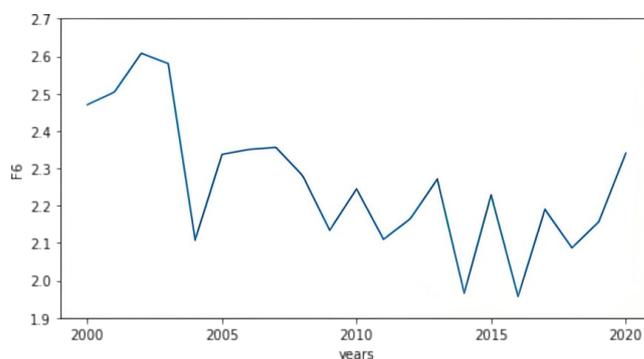

Figure 2. Wind speed fluctuations in June from 2000 to 2020.

This conclusion not only validates the scientific basis for index selection through data but also confirms the practical applicability of the algorithm presented in this paper. The algorithm can perform quantitative risk

assessment and claims calculation for insurance based on the fluctuation patterns of average June wind speeds, directly serving actual insurance operations. It provides a technical solution for risk management that combines scientific rigor with practical utility, demonstrating the transformative value of the research findings.

Advantages of rice weather index insurance empowered by the integration of Relaxed Lasso and blockchain

Resolving information asymmetry challenges

The openness and transparency of blockchain enable farmers to access relevant data and usage information about agricultural insurance products, as well as historical transaction details, thereby promoting transparency in agricultural insurance products. Simultaneously, insurance companies can obtain policyholder information such as personal details, credit history, and insured farmland data, effectively deterring insurance fraud. Furthermore, regulatory nodes within the blockchain facilitate real-time, effective business monitoring, enhancing information security and reliability.

Reducing transaction costs

On one hand, compared to traditional agricultural index insurance products, the improved version eliminates the need for intermediaries during contract signing between farmers and insurers. Farmers and insurers can conduct peer-to-peer transactions, requiring only the insurer to issue electronic policies and farmers to complete and upload forms, significantly reducing underwriting costs for insurers. On the other hand, smart contract technology enables automated claims processing. When weather data uploaded by meteorological stations is verified by the blockchain system and found to meet claim criteria, compensation is automatically disbursed to eligible farmers. Smart contracts not only resolve delays in payouts but also effectively reduce verification costs.

Boosting market promotion

The incentive mechanism designed for the improved agricultural index insurance can motivate users to a certain extent, increasing farmers' willingness to share information. This achieves secondary promotion of the product, stimulating market demand while reducing promotional costs. The product also establishes a referral system among acquaintances. Trust is more readily established among acquaintances, who often share similar social circles, cultural backgrounds, and consumption needs. Leveraging this referral mechanism enhances farmers' confidence in the insurance product and accelerates the expansion of promotional activities.

Reducing basis risk

The Relaxed Lasso algorithm identifies the most suitable indices for claims assessment, enhancing the accuracy of rice yield loss calculations and providing a more realistic reflection of disaster-induced damage. During claims processing, compensation for affected farmers is based on more precise data metrics, significantly reducing basis risk and largely meeting the needs of rice farmers.

Conclusion

In summary, this study addresses the challenges faced by traditional weather index insurance for rice cultivation. These challenges include information asymmetry, high basis risk, high operational costs, and difficulties in promotion. The study develops a systematic solution to these issues through technological innovation and mechanism optimization. The use of the Lasso algorithm optimizes the insurance index model. Leveraging blockchain technology, a decentralized trading system and smart contracts were established, while innovative incentive mechanisms and referral programs effectively enhance the promotion effectiveness of insurance products. This research not only enriches practical theories in agricultural risk management but also provides actionable pathways for reducing cultivation risks and optimizing insurance product supply in major rice-producing regions, aligning with the demands of high-quality agricultural economic development. However, this study has limitations: It is based solely on the case of Anhui Province and has not been expanded to a national scale, leaving regional applicability to be verified.

With the continuous advancement of technology, an increasing number of high-end or emerging technologies are being applied to insurance products. Therefore, the subsequent R&D upgrades of this study should not be confined to merely updating existing technologies but should also reasonably incorporate more advanced technologies. In the future, this research can integrate genetic testing technology to predict

whether rice yields will be reduced due to genetic issues, or to intervene early against potential rice diseases. This will prevent yield losses caused by meteorological factors, reduce policyholder claims probabilities, and help insurance companies lower costs - achieving a win-win outcome.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Yang, L., Wang, Z., Lee, J. I., Wang, T. Y. (2025) How does investment in agricultural insurance promote agricultural development? Mediating effect of green total factor productivity. *Finance Research Letters*, 81, 107485.

[2] Fang, L., Hu, R., Mao, H., Chen, S. (2021) How crop insurance influences agricultural green total factor productivity: evidence from Chinese farmers. *Journal of Cleaner Production*, 321, 128977.

[3] Wijesena, S., Pradhan, B. (2025) Advancements in weather index insurance: a review of data-driven approaches to design, pricing and risk management. *Earth Systems and Environment*, 9(3), 2355-2379.

[4] Sun, Q., Yang, Z., Che, X., Han, W., Zhang, F., Xiao, F. (2018) Pricing weather index insurance based on artificial controlled experiment: a case study of cold temperature for early rice in Jiangxi, China. *Natural Hazards*, 91(1), 69-88.

[5] Wen, Y. W. J., Ponnusamy, R. R., Kang, H. M. (2019) Application of weather index-based insurance for paddy yield: the case of Malaysia. *Int. J. Adv. Appl. Sci*, 6, 51-59.

[6] Luo, T. Y. (2025) The Weather Index Insurance Scheme for Crops: Insights from India. *Journal of Agricultural Sciences*, 31(3), 590-611.

[7] Ji, X., Chen, J., Zhang, H. (2024) Agricultural specialization activates the industry chain: Implications for rural entrepreneurship in China.

Agribusiness, 40(4), 950-974.

[8] Omar, I. A., Jayaraman, R., Salah, K., Hasan, H. R., Antony, J., Omar, M. (2023) Blockchain-based approach for crop index insurance in agricultural supply chain. *IEEE Access*, 11, 118660-118675.

[9] Ye, L. (2025) Digital economy and high-quality agricultural development. *International Review of Economics & Finance*, 99, 104028.

[10] Ma, W., McKay, A., Rahut, D. B., Sonobe, T. (2023) An introduction to rural and agricultural development in the digital age. *Review of Development Economics*, 27(3), 1273-1286.

[11] Sinnarong, N., Kuson, S., Nunthasen, W., Puphoung, S., Souvannasouk, V. (2022) The potential risks of climate change and weather index insurance scheme for Thailand's economic crop production. *Environmental Challenges*, 8, 100575.

[12] Xu, X., He, Y. (2024) Blockchain application in modern logistics information sharing: a review and case study analysis. *Production Planning & Control*, 35(9), 886-900.

[13] Wu, S., Cheng, H., Qin, Q. (2024) Physical delivery network optimization based on ant colony optimization neural network algorithm. *International Journal of Information Systems and Supply Chain Management (IJISSCM)*, 17(1), 1-18.

[14] Liu, S., Cheng, H. (2024) Manufacturing process optimization in the process industry. *International Journal of Information Technology and Web Engineering (IJITWE)*, 19(1), 1-20.