



Effectiveness evaluation of the mechanism of agricultural cooperatives linking farmers and farmers: A study based on structural equation modeling in northern Anhui

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SUMMARY: *In this paper, a unified framework of data extraction, variable coding, structural equation modeling and evaluation output is constructed around the evaluation of the mechanism of agricultural cooperatives in northern Anhui. The dataset integrates 84 cooperatives, 612 valid samples of farmers, questionnaires of farmers and village statistics from six prefecture-level cities in northern Anhui, and contains 21 observed variables and 4 potential dimensions. The study used expectation maximization to complete missing values, robust standardization of continuous variables, sequential coding of rank variables, and maximum likelihood estimation and 5000 Bootstrap sampling to complete parameter identification. The median value of comprehensive effectiveness of the six cities in northern Anhui was concentrated in the range of 65.0%-75.0%. The average values of comprehensive effectiveness, interest connection and participation response of comprehensive service cooperatives were 76.0%, 82.0% and 72.0%, respectively. The comprehensive explanation degree reached 67.0%.*

KEYWORDS: *Agricultural cooperatives; Structural equation model; Feature encoding; Path relationship modeling*

1 Introduction

Under the background of continuous rural revitalization and accelerated restructuring of agricultural management methods, agricultural cooperatives have become an important carrier connecting small farmers with modern agricultural systems. In northern Anhui, the cultivated land is concentrated, the planting structure is stable, and the labor flow is frequent. The organizational role of cooperatives in the unified purchase of agricultural materials, technical services, order connection, bottom-guaranteed purchase and income distribution is relatively prominent. At the same time, multi-source data such as contract performance, service frequency, transaction scale, dividend record, training participation and farmer feedback were continuously collected from the activities of joint farmers and farmers. If only relying on experience to judge the driving effect of cooperatives, it is difficult to accurately present the internal relationship between organizational operation, service embedding, interest linkage and farmer response. The introduction of computer-supported data processing, variable coding and structural relationship modeling into the evaluation of joint agricultural belt and farm mechanism can transform scattered records into calculable, comparable and verifiable analysis objects, and provide more stable quantitative basis for regional cooperative governance and policy adjustment.

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<https://doi.org/10.65102/is2026273>

Focusing on the application of agricultural data and farmer behavior recognition, related research has formed a good technical foundation. Kolapo et al. studied the impact of exposure to agricultural smartphone applications on the adoption behavior and operational efficiency of small farmers in Nigeria, indicating that digital access conditions would change the decision-making quality and production performance of farmers [1]. Adereti et al. analyzed the behavior characteristics of farmers' participation in the machine learning agricultural decision support system, and proposed that data understanding ability, trust level and usage threshold jointly affect the implementation effect of the system [2]. Uyar et al. studied the value creation process of agricultural data, and pointed out that multi-source data integration, feature screening and sharing mechanism are important pivots to release the value of agricultural data [3]. Dibbern et al. sorted out the main driving factors and constraints of digital agricultural technology adoption, and believed that organizational environment, infrastructure and benefit perception would simultaneously act on the technology acceptance process [4]. Sullivan et al. conducted research on the trust formation mechanism in agricultural data sharing, and proposed that transparent governance and data traceability structure can help to improve collaborative willingness [5]. Chin et al. proposed a real-time optimization and management framework for digital agriculture systems, which provides a computing platform reference for dynamic decision support in agricultural scenarios [6]. Lanucara et al. developed a cyberspace decision support system for precision agriculture, which shows that spatial data organization and online analysis tools can enhance the accuracy of regional management unit division [7]. Hasan et al. combined the Internet of things and blockchain into the agricultural trusted security system, demonstrating the application potential of trusted data circulation and process trace in agricultural collaborative governance [8]. The existing results provide method inspiration for the data evaluation of the mechanism of agricultural cooperatives, but the multi-dimensional relationship recognition in the cooperative scene in North Anhui still needs to be combined with the structural equation model for targeted expression.

Based on this, this paper constructs a structural equation model analysis framework that integrates data extraction, index coding, path estimation and efficiency measurement for the scene of agricultural cooperatives in North Anhui. In this study, cooperative operation records, farmer questionnaires, village-level statistical data and service accounts were incorporated into the unified data matrix, and the organizational operation ability, service embedding degree, interest connection strength and farmer participation response were jointly expressed. The key associations affecting effectiveness were identified by means of observation load test, regional difference comparison, comprehensive score distribution and repeated sampling stability analysis. The focus of this paper is not on the description of general phenomena, but on the computational expression of regional samples and the characterization of structural relations. At the theoretical level, the mechanism of joint farming and belt farming was transformed into a quantifiable latent variable relationship network. At the application level, the research results can provide a reviewable data basis for the classification and identification of cooperatives, the judgment of resource investment and the adjustment of rural revitalization policies in northern Anhui. Compared with single index statistics, mean comparison or empirical grouping judgment, this paper pays more attention to transforming discrete survey items, rank variables and behavior records into a unified coding form, and testing direct effects, indirect effects and explanatory strength in the same model, so that the mechanism identification is based on clearer variable relationships and regional empirical basis. On this basis, the following chapters will carry out literature review, variable expression, path modeling, experimental verification and result discussion in turn, forming a complete research chain.

2 Literature Review

2.1 Research status of the mechanism of agricultural cooperatives combining farmers with farmers and its effectiveness evaluation

The formation and operation of the mechanism of agricultural cooperatives with farmers and farmers has gradually shifted from experience judgment to structure identification and efficiency measurement supported by data. In existing practice, many regions have begun to incorporate cooperative member information, service records, order performance, dividend accounts and farmer feedback into the scope of digital management, which is used to describe the actual performance of cooperatives in driving farmers to increase income, stabilize production and participate in coordination. Relevant data show that about 45% of the cooperatives with basic information conditions have established electronic ledger or online registration system. Among them, the data retention rate of the cooperatives in the main grain producing areas of North Anhui is relatively high in the purchase and sale records, input distribution and income distribution, with some samples reaching more than 60%. This kind of data accumulation provides a computable basis for the quantitative evaluation of the joint agriculture and banding mechanism. However, there are still obvious differences in data structure, variable caliber and record granularity among different cooperatives, so the effectiveness identification increasingly depends on the uniform data organization and model expression.

Rizwan et al. studied the process of greenhouse control and fruit distribution tracking in the blockchain environment, and proposed to enhance the traceability of agricultural collaboration links through trusted records and chain traces [9]. Thomopoulos et al. studied the application of fuzzy logic and Internet of things in small intelligent greenhouse, and proposed that real-time state perception and rule calculation can improve the response accuracy of agricultural operation process [10]. Ayadi et al. studied the unified publishing method of agricultural document semantic annotation, and proposed that the knowledge graph was used to organize heterogeneous agricultural information, which could enhance the expression ability of semantic association between agricultural data [11]. Bandaru et al. studied the automatic quality control of soil moisture time series data and proposed that a deep learning quality control system can improve the availability and consistency of original agricultural data [12]. Although these studies do not directly focus on the mechanism of agricultural cooperatives, they have provided a clear method reference for the evaluation of cooperative mechanism in terms of data trusted storage, state perception, semantic organization and quality verification in agricultural scenarios.

Inspired by the above studies, the evaluation of the joint farmer-farmer mechanism no longer focuses on the comparison of single income, but pays more attention to the joint expression of organizational behavior, service supply, benefit linkage and farmer response by computer means. Existing research shows that after the introduction of variable coding, semantic association and quality control, the analyzability of cooperative operation records is significantly improved, and the multi-dimensional evaluation results are closer to the actual connection state, which provides more stable data support for the identification of regional cooperative efficiency. On this basis, the establishment of an interpretable, testable, and comparable structural equation evaluation framework around the mechanism of cooperative joint farming and belt farming in northern Anhui has become a clear direction in the current data research, and further lays a methodological foundation for subsequent path estimation and efficiency output.

2.2 Lack of research on identification of influencing factors and structural equation analysis method of joint agriculture and belt agriculture mechanism

In the research on the effectiveness evaluation of the joint agricultural Belt and Farm mechanism, the identification of influencing factors and structural equation analysis have formed a certain accumulation, but the existing writing methods still have obvious limitations in the level of data organization, variable expression and computational modeling. Among the existing studies, more than half of them still rely on single questionnaire aggregation and average comparison as the main basis, and less than 40% of the studies can incorporate cooperative operation records, farmers' behavior data and village-level statistical information into the unified analysis framework. Although this method is convenient to describe the connection state, it is difficult to present the multi-layer relationship among organization operation, service provision, profit distribution and participation response.

In terms of variable processing, many studies directly follow the general social survey indicators, and the number of studies that truly combine cooperative transaction records, service frequency, contract performance trajectory and income account information to construct observation variables is small, which leads to the lack of detailed expression of the calculation of the mechanism of joint farmers and farmers. In terms of model use, although some studies use structural equation models, most of them stay in static path testing, the connection between latent variable setting and original data sources is weak, and the coding rules, missing values repair and abnormal sample screening process lack uniform standards, which limit the interpretability and regional comparability of the model. From the existing sample distribution, cross-regional studies account for about 30%, and most of the analysis is carried out around a single county or a single type of cooperative, and the research that can take into account regional differences, organizational levels and farmer heterogeneity is still few. The overall migration adaptation capability is limited.

Shahab et al. studied the early livestock disease monitoring system based on the Internet of Things, and proposed that the continuous perception and real-time transmission mechanism could improve the timeliness of state recognition in agricultural scenes [13]. Goldenits et al. studied the application of agricultural digital twin based on reinforcement learning, and proposed that dynamic feedback and virtual-real mapping can enhance the decision-making and adaptation ability of complex agricultural processes [14]. Liu et al. studied the machine learning time series prediction method of agricultural greenhouse environmental parameters and pointed out that feature selection, time series dependence and model collaboration have a direct impact on the stability of the results [15]. Peng et al. studied the application status of blockchain smart contracts in the agri-food industry, and proposed that trusted records and automatic rule execution can help improve the transparency of cross-agent collaboration process [16]. These studies show that data recognition, dynamic modeling and credible circulation in agricultural scenarios have strong technical support, while the evaluation of joint agriculture and belt agriculture mechanism still needs to further strengthen the coding of multi-source variables, the description of path relationships and the computational expression of structural equation model, so as to more accurately reflect the real effectiveness of cooperatives in driving farmers in northern Anhui.

2.3 Development direction of data evaluation of joint agriculture and agriculture mechanism supported by computer

Based on the above research status and method adaptation, the subsequent development of the data evaluation of the joint agriculture and belt agriculture mechanism needs to further

strengthen the deep combination of computer technology and cooperative governance scenarios. The existing assessment writing methods have been able to show part of the differences between farmers driven by cooperatives, but future research should pay more attention to the continuous connection between multi-source data access, unified coding of variables, expression of relationship networks and interpretation of model results. For the areas with dense distribution of cooperatives, diverse management structures and obvious differentiation of farmers' participation levels in northern Anhui, it is difficult to fully express the actual operation status of the mechanism of joint agriculture and belt agriculture by single questionnaire summary or static mean comparison. A more suitable development path is to organize cooperative transaction records, service ledgers, dividend data, farmer feedback and village-level statistical data into a unified data matrix, and on this basis to complete feature screening, latent variable mapping and path estimation, so as to improve the fineness of mechanism identification and the comparability of evaluation output.

Chen et al. studied the integration of interpretable artificial intelligence and blockchain in smart agriculture, and proposed that decision-making transparency and data trusted protection should enter the computing framework of agricultural scenarios at the same time [17]. de Andrade Porto et al. studied the application of fewsample learning and meta-learning in agriculture, and proposed that constructing a robust model under the condition of limited sample size had high methodological value [18]. Gebresenbet et al. studied the application concept of integrated digital technology in future smart agriculture, and proposed that multi-technology collaboration can enhance the linkage analysis ability of agricultural systems [19]. Hafeez et al. studied the implementation path of UAV in farmland monitoring and spraying, and proposed that high-frequency acquisition and spatial coverage could provide more fine-grained data support for agricultural analysis [20]. Chen et al. studied the data-driven decision-making scheme in multi-area greenhouse light environment control, and proposed that zoning modeling and dynamic adjustment mechanism could improve the pertinency of agricultural decision-making [21]. These studies show that trusted storage, few-shot modeling, integrated perception and data-driven decision-making in agricultural scenarios have a good technical foundation, and the next focus of the evaluation of joint agricultural mechanism should be on the calculation and expression of multi-layer variables and the fine description of structural relationships.

To facilitate the understanding of the adaptation differences of different evaluation paths, Table 1 shows the comparison between several types of common ideas and the development direction of this paper.

Table 1: Comparison of the datafication evaluation paths of the joint agricultural Belt and Farm mechanism

Evaluation Path	Data Foundation	Computational Expression	Adaptation Characteristics
One-Time Questionnaire Aggregation	Questionnaire items	Frequency statistics, mean comparison	Convenient for describing overall differences, but weak in structural representation
Experience-Based Group Judgment	Cooperative categories, farmer types	Manual stratification, rule-based judgment	Easy to implement, but limited in cross-sample consistency
Static Regression Analysis	Survey data, partial operational indicators	Linear relationship estimation	Can identify local effects, but is less capable of presenting multi-level pathways
Conventional Structural Equation Analysis	Questionnaire variables, manually coded indicators	Latent variable estimation, path testing	Has overall analytical capability, but the scope of data access can still be expanded
Computer-Supported Data-Driven Evaluation	Transaction records, service ledgers, dividend data, feedback information, village-level statistics	Multi-source encoding, path modeling, evaluation output	More suitable for characterizing linkage strength, response differences, and mechanism stability

As shown in Table 1, future data-based evaluations are no longer limited to describing whether cooperatives drive farmers, but more emphasis is placed on identifying structural links between drive strength, linkage stability, participation response, and revenue transmission under unified coding conditions. Along this direction, structural equation model and computer supported data organization can form a closer combination, and provide a clearer quantitative basis for the classification and policy adjustment of cooperatives in northern Anhui. The evaluation process will also be closer to the real operation state of the region.

3 Research Methods

3.1 Overview of the overall research framework

This study constructs a data research framework consisting of data access, variable expression, path modeling and effectiveness output for the effectiveness evaluation task of the agricultural cooperatives in northern Anhui. The goal of the framework is not to stay in the static description of the cooperative driving effect, but to organize the cooperative operation records, farmer questionnaires, village-level statistical data and service accounts as a unified calculation object, and complete the information integration, relationship identification and result generation in the same analysis chain, so as to improve the interpretability and regional comparability of the evaluation of the mechanism of joint farming and belt farming.

As shown in Fig. 1, the overall framework unfolds in the order of "collection of raw data - coding of evaluation variables -- estimation of structural relations -- output of comprehensive effectiveness". The data access layer is responsible for collecting cooperative transaction records, dividend information, service frequency, farmer participation records and rural basic

statistical data, and deduplication, completion and standardization. The variable expression layer maps the core dimensions of organization operation, service embedding, interest connection and participation response into the set of observed variables, and forms the input structure into the model through hierarchical coding and matrix representation. The path modeling layer takes the structural equation model as the core, estimates the direct effect, indirect conduction and mediation relationship between the latent variables, and combines the fitting index to complete the model verification. The efficiency output layer forms the comprehensive evaluation results of the cooperative joint agricultural belt agricultural mechanism according to the path coefficient, explanation strength and dimension score, and supports the horizontal comparison between different regions and different organization types.

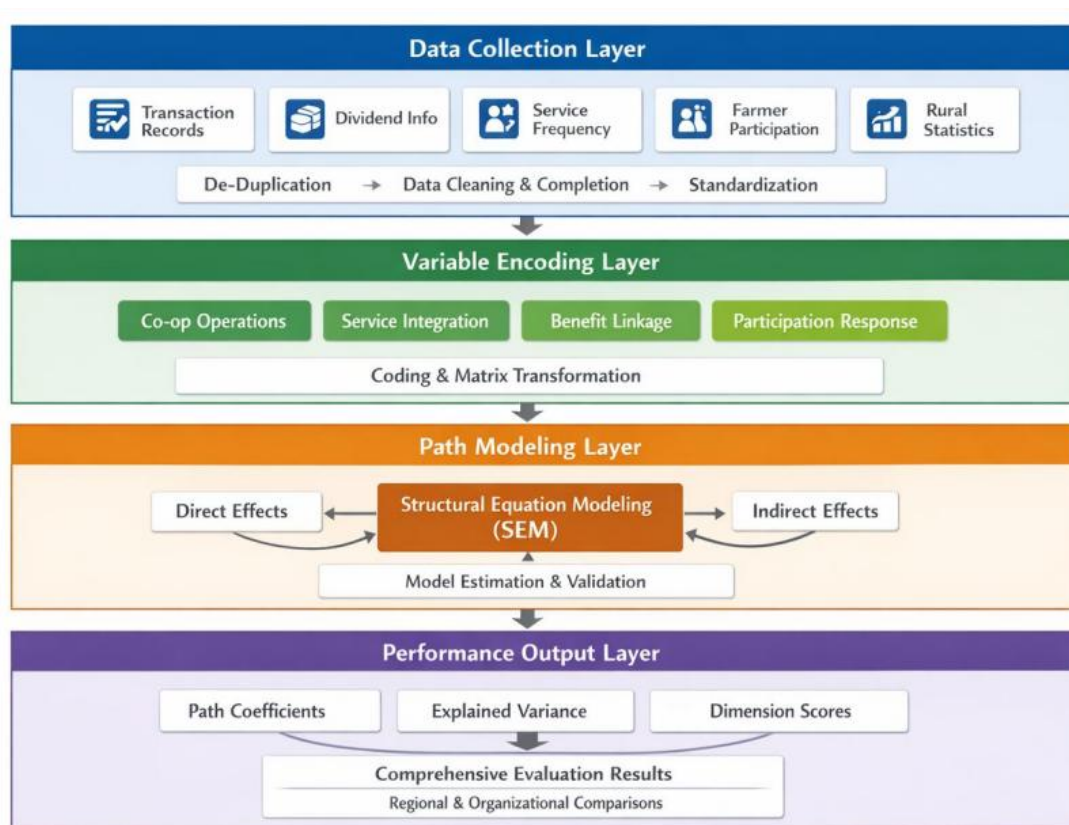


Figure 1: The overall research framework of the data evaluation of the mechanism of agricultural cooperatives in northern Anhui

The framework maintains the realistic pertinence of agricultural cooperative research in methodology, and also absorbs the technical advantages of the computer field in data organization, variable coding and structure identification. Each module is not arranged in isolation, but gradually connected in a unified data flow, so that the original survey data can be transformed into structural significance of the evaluation results. Through such an organizational way, the follow-up research can not only identify the main role path of cooperative farmers in northern Anhui, but also provide a more stable quantitative basis for the judgment of resource investment and regional governance adjustment. At the same time, the framework reserved the interface of sample update and index expansion, which was convenient to realize the functions of repeated calculation, result review and comparative analysis between different years, different cooperative types and different towns.

3.2 Extraction and coding expression of effectiveness evaluation variables of the mechanism

The effectiveness of the mechanism is not directly attached to a single statistical index, but scattered in the cooperative management records, service lists, farmer questionnaires, order performance, income return and village-level statistical data and other information. If only a single item is used to describe the driving degree of cooperatives, only fragmented results can be obtained, and it is difficult to reflect the continuous structure between organization operation, service supply, interest connection and farmer response. Based on this, this paper divides variable extraction into five steps: original record screening, observation variable construction, direction unification, rank coding and matrix expression, so that data from different sources can complete comparable calculation in the same analysis space. The processed variable system not only retains the realistic characteristics of the cooperative driving farmers, but also meets the requirements of the structural equation model for the stability, identifiability and interpretation consistency of the input matrix.

In order to eliminate the dimensional differences of various continuous indicators before entering the unified analysis framework and maintain the relative fluctuation range between different samples, this paper adopts robust standardization processing for the original variables, which is expressed as follows:

$$z_{ij} = \frac{x_{ij} - \text{Med}(x_j)}{\text{IQR}(x_j) + \varepsilon} \quad (1)$$

Here, x_{ij} represents the value of the i sample on the j original index, $\text{Med}(x_j)$ represents the median of index j , $\text{IQR}(x_j)$ represents the interquartile range, and ε is a smoothing term set to prevent the denominator from going to zero. Equation (1) does not directly adopt the mean-variance standardization, but retains the median and interquartile structure which is more robust to extreme values, and is more suitable for dealing with data with strong skewness such as transaction volume, service times and income return proportion of cooperatives.

In order to transform the service supply intensity of cooperatives to farmers from scattered records into computable variables, this paper constructs a service embedding index based on five types of services: training, unified purchase, consignment sale, technical guidance and financial coordination.

$$S_i = \sum_{k=1}^K \omega_k \cdot \ln(1 + f_{ik}) \cdot (1 + \eta_k c_{ik}) \quad (2)$$

Here, f_{ik} represents the frequency of the i sample receiving the k type of service, c_{ik} represents the continuous coverage coefficient of this type of service, ω_k represents the weight of service importance, and η_k represents the continuous adjustment coefficient. In Equation (2), continuous coverage term is added in addition to frequency, so as to avoid excessive amplification of services with simple high frequency but short duration, and to make long-term embedded services obtain weights more consistent with reality in the expression of variables.

In order to incorporate income return, order performance and the degree of guaranteed acquisition into the same linkage dimension, this paper further constructs the variable of benefit linkage strength, which is expressed as follows:

$$B_i = \alpha_1 r_i + \alpha_2 o_i + \alpha_3 g_i + \alpha_4 \sqrt{r_i o_i} \quad (3)$$

Here, r_i represents the revenue return proportion of the i sample, o_i represents the order fulfillment rate, g_i represents the guaranteed acquisition fulfillment level, and α_1 to α_4 are the normalized weights. Equation (3) not only considers the independent contribution of each index, but also adds the synergistic term $\sqrt{r_i o_i}$ to depict the enhancement effect formed when "income return" and "order stability" are high at the same time, so as to make the expression of the benefit transmission relationship between joint farmers and farmers more complete.

In order to stably map the rank items in the farmer questionnaire to the numerical space and avoid the expression deviation caused by the inconsistent rank width of different items, this paper uses the quantile order coding function to transform the subjective variables:

$$Q_{ij} = \frac{1}{M_j} \sum_{m=1}^{M_j} m \cdot I(u_{ij} = m) + \frac{\rho_j}{M_j - 1} \sum_{m=1}^{M_j-1} I(u_{ij} > m) \quad (4)$$

Here, u_{ij} represents the original response of the i sample on the j rank item, M_j represents the maximum rank of the item, $I(\cdot)$ is the indicator function, and ρ_j represents the correction parameter of item discrimination. In Equation (4), rank position and discrimination correction are incorporated into the coding process at the same time, so that items such as "trust", "participation intention" and "cooperation satisfaction" not only maintain the order relationship, but also reflect the differences in recognition ability of different items.

In order to compress redundant variables and enhance the explanatory efficiency of observations for latent dimensions, this paper introduces a weighted screening function after the encoding is completed to give a comprehensive score for each candidate variable:

$$G_j = \lambda_1 |\rho(y, x_j)| + \lambda_2 MI(x_j, y) - \lambda_3 \frac{1}{p-1} \sum_{h \neq j} |\rho(x_j, x_h)| \quad (5)$$

Here, $\rho(y, x_j)$ represents the Pearson correlation coefficient between the candidate variables and the target dimension, $MI(x_j, y)$ represents the mutual information value, λ_1 to λ_3 are the conditioning parameters, and p is the total number of candidate variables. Equation (5) simultaneously considers three aspects: linear correlation, information contribution and variable redundancy, which can avoid multiple indicators with similar meanings repeatedly entering the model, thus maintaining the compactness and interpretability of the input matrix.

In order to organize the multi-source variables into a unified input matrix that can enter the structural equation estimation finally, this paper establishes the following matrix expression after the completion of standardization, construction, coding and screening:

$$X = [Z \parallel S \parallel B \parallel Q] \in \mathbb{R}^{n \times p}, \quad W = \text{diag}(G_1, G_2, \dots, G_p), \quad X^* = XW \quad (6)$$

Here, Z represents the set of standardized continuous variables, S represents the set of service embedding variables, B represents the set of benefit connection variables, Q represents the set of ordered coding variables, W is the diagonal matrix of variable weights, and X^* is the final input matrix after weighting. Equation (6) indicates that the decentralized records have been converted into a standard input structure that can be used for path identification and efficiency measurement, and it also means that the original information at the three levels of cooperatives, farmers and villages has been expressed in the same calculation

plane.

Through the above processing, the effectiveness evaluation variables of the mechanism no longer stay in the empirical list, but form a complete extraction chain of "original record - numerical mapping - weight compression - matrix expression". The variable system established in this way can not only undertake the actual details of the cooperative operation in north Anhui, but also meet the requirements of data continuity, direction consistency and structure stability for subsequent path modeling. At this point, the computational expression of the variable level has been completed, and the subsequent structural equation model can carry out the identification of the latent variable relationship, the decomposition of the mediating effect and the measurement of the comprehensive efficiency on this basis, so as to promote the mechanism of joint agriculture and agriculture from a describable object to a computable object.

3.3 Path relationship modeling of joint agriculture belt agriculture mechanism based on structural equation model

After completing the variable extraction and coding expression, the research focus of the joint agricultural belt and farm mechanism enters the stage of structural relationship identification. In this paper, structural equation model is used to construct the path network of "organization operation -- service embedding -- benefit connection -- participation and response -- comprehensive effectiveness". The driving effect of cooperatives on farmers is no longer regarded as a one-way effect, but as a structural process of multiple potential dimensions coupling together and layer by layer conduction. The advantage of this model is that it can accommodate observation variables and potential variables, direct and indirect effects, measurement layer and structure layer at the same time, so as to be closer to the actual operation logic of agricultural cooperatives in northern Anhui, and make the evaluation conclusion have stronger structural explanatory power.

In order to make the observed variables that have been coded stably mapped to the latent dimension, and keep the direction of each item in the measurement layer unified and the load clear, this paper first establishes the measurement model:

$$x = \Lambda_x \xi + \delta, \quad y = \Lambda_y \eta + \varepsilon \quad (7)$$

Here, x denotes the exogenous observation variable vector, y denotes the endogenous observation variable vector, Λ_x and Λ_y are the factor loading matrices, ξ denotes the exogenous latent variable, η denotes the endogenous latent variable, and δ and ε are the measurement residuals. The significance of Equation (7) is to confirm whether the observation items such as service record, income return and participation feedback can be stably attributed to the corresponding potential dimension, and provide a reliable measurement basis for subsequent structural path estimation.

In order to further characterize the causal conduction direction between each potential dimension, and to write the association between the internal organizational capacity and external driving efficiency of cooperatives into an estimable structural system, this paper constructs the following structural equation:

$$\eta = B\eta + \Gamma\xi + Kc + \zeta \quad (8)$$

Here, B represents the path coefficient matrix between endogenous latent variables, Γ represents the influence matrix of exogenous latent variables on endogenous latent variables, c represents the region correction vector, K is the region perturbation coefficient matrix, and ζ is the structural residual. Compared with the general structural model, the additional regional

correction term is introduced in Equation (8), in order to make the sample differences between different counties and different types of cooperatives in northern Anhui more secure in the same estimation framework, so as to avoid excessive deviation of path judgment caused by local environmental differences.

In order to identify the conduction status of farmer participation between organization operation, service embedding and comprehensive effectiveness, and to incorporate indirect effects into a unified structural interpretation, this paper defines the total effect matrix as follows:

$$T = (I - B)^{-1}\Gamma + (I - B)^{-1}Kc \quad (9)$$

Here, I is the identity matrix and T represents the total effect matrix of exogenous latent variables leading to the comprehensive effectiveness. Equation (9) puts the direct path and the indirect path generated by participation response and income linkage in the same expression, so that the core relationship of "how the organizational capacity of cooperatives affects farmers through service embedding to drive effectiveness" can be clearly decomposed, and the subsequent effectiveness measurement no longer stays on the surface comparison of the level of a single path.

In order to ensure that the model estimation takes into account the sample fitting degree, covariance structure stability and parameter identifiability, this paper uses the maximum likelihood objective function with penalty term to solve the problem, which is expressed as follows:

$$F(\theta) = \ln |\Sigma(\theta)| + \text{tr}(S\Sigma^{-1}(\theta)) - \ln |S| - p + \lambda \|\Gamma\|_F^2 \quad (10)$$

Here, $\Sigma(\theta)$ represents the implied covariance matrix of the model, S represents the sample covariance matrix, p represents the dimension of the observed variable, $\|\Gamma\|_F^2$ is the Frobenian norm penalty term of the path matrix, and λ is the regularization parameter. Equation (10) adds a path contraction constraint on the basis of the general maximum likelihood estimation, which helps to control the model expansion caused by too many weak paths, and makes the structural equation model maintain better stability in the cooperative data with limited sample size but many relationship levels.

In order to present the internal logic of the proposed path model more intuitively, Fig. 2 places the mutual position, measurement entry and efficacy exit of each potential dimension in the same frame. In the figure, the left side shows three exogenous latent variables of organization operation, service embedding and interest linkage, the middle part shows the intermediary layer of farmer participation and response, and the right part shows the comprehensive effectiveness of the mechanism of linking farmers with farmers. The lower observation variable groups correspond to business records, service accounts, income items and questionnaire feedback respectively, while the upper ones indicate the three support links of model estimation, fitting test and stability check. In this way, the diagram is not just an overview of the process, but a structured compression of the relationship between the measurement layer, the structure layer, and the output layer, which helps the reader to clearly see how each path enters the unified model and ultimately translates into a comprehensive performance evaluation.

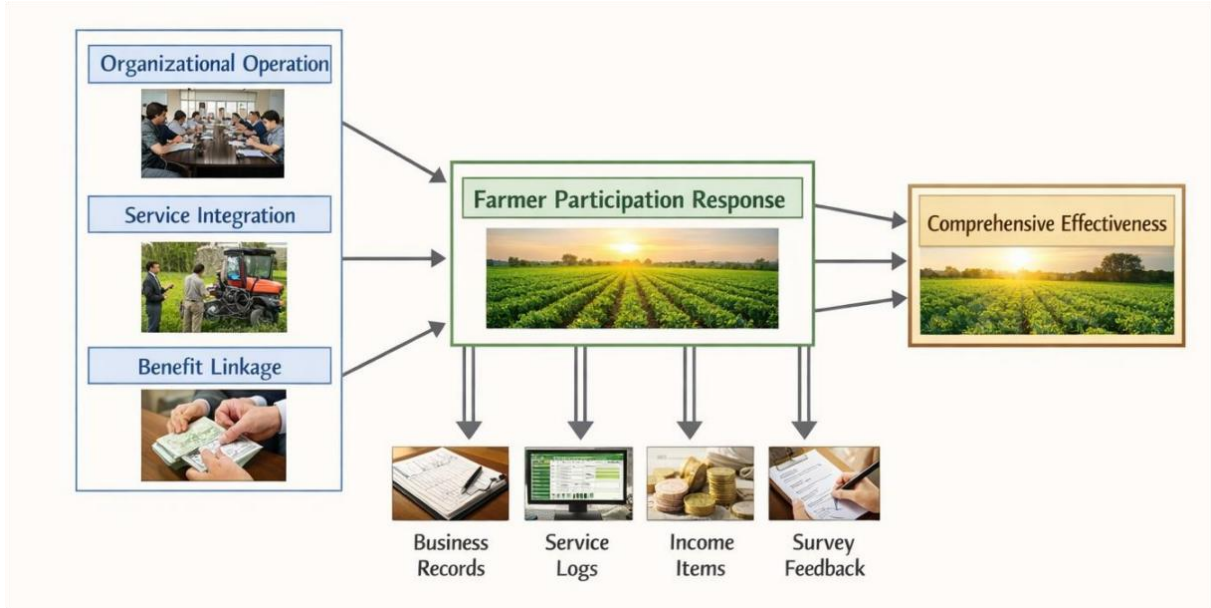


Figure 2: Modeling structure diagram of path relationship of joint agriculture belt agriculture mechanism

Based on the above modeling approach, the effectiveness of cooperative joint farming is no longer understood as a single point outcome, but is placed in a multi-level structure composed of latent variables, observation items and path coefficients. The model output can not only show which kind of factors have stronger effects on comprehensive efficiency, but also reveal whether these effects arrive directly or are transmitted gradually through farmer participation and income realization. The structural relationship network thus formed not only inherits the variable coding results completed in the previous section, but also provides a quantifiable, interpretable and decomsolvable model basis for the comprehensive measurement and evaluation output in the next section.

3.4 Effectiveness measurement and evaluation output of joint farming and belt farming mechanism

After the path relationship modeling was completed, the analysis of the mechanism turned to efficiency measurement and result generation. If we only stay at the level of standardized path coefficient, although it can explain the effect direction between latent variables, it is still difficult to form usable conclusions for cooperative governance and regional comparison. Based on this, this paper integrates the latent variable score, structural weight, regional correction and stability test into the same output system, and constructs a four-layer evaluation structure of "dimension score-comprehensive score-correction score-stability score". The results can not only explain the level of a cooperative with farmers, but also explain whether the level is driven by organization operation, service embedding, interest connection or farmer participation, so that the evaluation output has stronger interpretation depth and application value.

In order to convert the latent variable results in structural equation models into comparable dimension scores and maintain the direction consistency and numerical stability of each dimension on a unified scale, the following factor score functions are used:

$$h_{id} = \sum_{j=1}^{p_d} v_{dj} x_{ij}^* + \sum_{j=1}^{p_d} \sum_{l>j} \psi_{djl} x_{ij}^* x_{il}^* \quad (11)$$

Here, h_{id} represents the score of the i sample on the d latent variable dimension, v_{dj} represents the weight of the observed variable, ψ_{djl} represents the interaction correction term between the observations in the same dimension, and x_{ij}^* represents the index value after unified coding. Equation (11) not only retains the linear contribution of the observed variables, but also incorporates the interaction influence within the same dimension into the score calculation, so that the composite relationship such as service continuity and income stability can be reflected in the dimension measure.

In order to integrate multiple latent variable scores into a single comprehensive efficiency index of the joint farming and banding mechanism, while maintaining sufficient identification of high-contribution paths in the results, this paper constructs the following comprehensive measure function:

$$E_i = \sum_{d=1}^D \pi_d h_{id} + \sum_{a \neq b} \kappa_{ab} h_{ia} h_{ib} + \tau \cdot t_i^T \mathbf{1} \quad (12)$$

Here, E_i represents the comprehensive effectiveness score of the i sample, π_d represents the first-order weight of each dimension, κ_{ab} represents the dimension interaction coefficient, t_i represents the total effect vector obtained from the path model, and τ is the adjustment parameter of path strength. Equation (12) incorporates the level of latent variable, dimension coupling and structural path contribution into the comprehensive measure at the same time, so that the effectiveness score is no longer a simple weighting result, but an output value of the joint effect of structural relationship and dimension performance.

In order to establish a more equitable basis for horizontal comparison between different counties, different cooperative sizes and different crop management conditions in northern Anhui, this paper further introduces regional heterogeneity correction for the comprehensive efficiency index, which is expressed as follows:

$$E'_i = E_i - \phi_1 \Delta r_i - \phi_2 \Delta s_i - \phi_3 \Delta a_i + \phi_4 \Delta d_i \quad (13)$$

Here, Δr_i represents the bias of resource endowment, Δs_i represents the bias of organization size, Δa_i represents the bias of industrial structure, Δd_i represents the correction term of cooperation density, and ϕ_1 to ϕ_4 are the corresponding adjustment coefficients. The function of Equation (13) is to weaken the external influence of regional conditions and organizational volume on the efficiency judgment of cooperatives, so that the evaluation results can reflect the operation quality of the mechanism itself more centrally.

In order to test the stability of the corrected comprehensive score under repeated sampling conditions, this paper defines the evaluation stability as the joint function of score fluctuation and path deviation, as shown in Equation (14):

$$R_i = \exp \left\{ - \left[\frac{1}{B} \sum_{b=1}^B \left(\frac{E'_{ib} - \bar{E}'_i}{\bar{E}'_i + \tau} \right)^2 + \omega \cdot \frac{1}{B} \sum_{b=1}^B \|t_{ib} - \bar{t}_i\|_2^2 \right] \right\} \quad (14)$$

where R_i represents the evaluation stability of the i sample. B is the number of resampling. E'_{ib} denotes the corrected score at the b resampling; \bar{E}'_i denotes the mean corrected score; τ is a smoothing term. t_{ib} represents the total path effect vector at the b estimation. \bar{t}_i is its mean; Let ω be the path fluctuation penalty coefficient. Equation (14) simultaneously measures the dispersion degree of comprehensive score and the stability of path structure. The

closer the value is to 1, the more stable the evaluation result is.

In order to facilitate the understanding of the hierarchical composition of the evaluation output in this paper, Table 2 summarizes the meanings, sources and uses of various result items.

Table 2: Output structure of the effectiveness evaluation of the joint farm Belt Farm mechanism

Output Level	Main Content	Representation Form	Output Purpose
Dimension Score	Organizational operation, service embedding, benefit linkage, participation response	Standardized latent variable scores	Identify single-dimension strengths and weaknesses
Composite Score	Overall effectiveness of the farmer-linkage mechanism	Weighted aggregation index	Horizontal comparison among cooperatives
Adjusted Score	Results adjusted by region and scale	Heterogeneity-corrected index	Fair comparison across regions
Stability Indicator	Degree of fluctuation after resampling	Credibility score	Result verification and application judgment

Through the above measurement and output process, this paper finally forms not a single static score, but a multi-layer evaluation system that can be split, comparable and traceable. The performance of joint farmers and farmers of cooperatives can be seen from the dimension score to see the internal structure, from the comprehensive score to see the overall level, from the correction score to see the real position after excluding external deviations, and from the stability score to see the reliability of the evaluation results. The generated output results are not only suitable for single cooperative diagnosis, but also suitable for horizontal comparison between different counties in northern Anhui, and can provide a clear, stable and technically supported quantitative basis for subsequent experimental evaluation and empirical discussion.

4 Experimental Evaluation

4.1 Experimental Design

4.1.1 Dataset description

The data set of this study comes from 84 agricultural cooperatives and their associated farmers in six prefecture-level cities in northern Anhui, and the time range covers January 2022 to December 2024. The original data is composed of four parts: cooperative operating ledger, farmer questionnaire, villy-level statistical data and service records. After field alignment, duplicate sample elimination, missing item completion and outlier compression, a unified sample library can be formed for structural equation analysis. Finally, 612 samples of effective farmers, 84 samples of cooperatives and 21 observation variables were retained, which covered four dimensions of organization operation, service embedding, interest connection and participation and response.

To facilitate the explanation of the composition structure and source hierarchy of the data set, Table 3 summarizes the sample size, variable range and regional coverage.

Table 3: Summary of dataset composition and structure

Attribute	Description
Time Range	January 2022 to December 2024
Regional Scope	Six prefecture-level cities in northern Anhui
Cooperative Samples	84 cooperatives
Valid Farmer Samples	612
Number of Observed Variables	21
Variable Dimensions	Organizational operation, service embedding, benefit linkage, participation response
Data Sources	Operation ledgers, farmer questionnaires, village-level statistics, service records

From the perspective of spatial coverage, the sample of main grain producing areas accounted for 58.3%, the part-time operation cooperatives accounted for 26.2%, and the characteristic planting and breeding cooperatives accounted for 15.5%. The sample structure was basically consistent with the distribution characteristics of cooperatives in northern Anhui. In order to ensure that the data can enter the unified computing framework, the continuous variables are processed by robust standardization, and the rank variables are transformed by sequential coding. The records of the cooperative level and the farmer level are merged into a hierarchical matrix by matching the primary key, and three types of control information are retained: regional identification, cooperative type and business category. The samples were divided into modeling set and validation set according to 7 : 3. The modeling set was used to estimate the measurement model and structural model, and the validation set was used to check the robustness and review the results. Table 3 summarizes the composition, source and variable structure of the data set, which can completely support the effectiveness evaluation task of the joint agriculture and belt agriculture mechanism in northern Anhui, and support the subsequent group comparison and review. The data source chain is also clear, and the regional representation is strong, which is suitable for subsequent extended analysis.

4.1.2 Configuration of structural equation model parameters

The structural equation model in this study uses a two-stage estimation strategy. In the first stage, the measurement model was tested, focusing on the load strength of each observation variable on the latent dimension and the definition of the measurement boundary. In the second stage, the structure estimation and stability review were carried out to identify the overall effect direction of organization operation, service embedding, benefit linkage and participation response on the effectiveness of the joint agricultural belt and farm mechanism. The model estimation was completed jointly in the Python data cleaning environment and AMOS path analysis environment, the missing values were completed by the expectation maximization method, and the abnormal samples were jointly screened according to the Mahalanobis distance and the standard residual.

In order to keep the parameter setting and judging caliber clear, Table 4 focuses on the estimation method, sampling method and main threshold.

Table 4: Summary of structural equation model parameter configurations

Parameter Item	Configuration Content
Estimation Method	Maximum Likelihood Estimation
Sampling Test	5,000 Bootstrap Resamples
Missing Value Handling	Expectation-Maximization Imputation
Outlier Screening	Mahalanobis Distance + Standardized Residuals
Minimum Number of Indicators Retained for Each Latent Variable	No fewer than 3
Standardized Factor Loading Threshold	Greater than 0.60
Composite Reliability Threshold	Greater than 0.70
Average Variance Extracted Threshold	Greater than 0.50

Maximum likelihood estimation was used to solve the parameters, and the mediation effect and path stability were tested by 5000 Bootstrap repeated sampling. In order to ensure the statistical reliability of the model setting, the standardized load, combined reliability, average variance extraction value and fitting index are used as the model quality test basis, and the stability of the model is rechecked by combining the repeated sampling results. In terms of parameter configuration, the latent variable retains at least three observation indicators, the standardized load is controlled above 0.60, the combined reliability is maintained above 0.70, and the average variance extracted value is maintained above 0.50. In addition, this paper sets regional grouping markers to compare the differences in path intensity and efficiency output of different county cooperative samples, and retains the correction index for subsequent model fine-tuning.

4.2 Experimental Results

In this section, the measurement quality, regional differences, repeated sampling stability and module contribution of the model are jointly tested based on 84 agricultural cooperatives and 612 effective farmer household samples in six cities in northern Anhui. The parameters were estimated using the maximum likelihood method, and the stability of the results was tested by 5000 Bootstrap repeated sampling. Figs. 3 to 7 and Tables 5 and 6 show the experimental results in terms of variable relationship distribution, observation load, regional sample differences, repeated sampling results, latent variable structure characteristics, cooperative type differences and module contributions, respectively.

To present the correspondence between benefit linkage and comprehensive effectiveness more intuitively, Fig. 3 shows the scatter distribution of both. The results show that the overall sample points are clustered along the direction of bottom left to top right, indicating that the higher the level of interest connection, the stronger the comprehensive effectiveness of the mechanism of cooperative joint farming and belt farming. The high-efficiency samples mainly concentrated in the interest linkage interval of 0.75 -- 0.90, and the corresponding comprehensive effectiveness mostly remained between 0.72 and 0.86. The medium samples are more distributed in the interval of 0.62 to 0.78, and the comprehensive validity is concentrated in the range of 0.60 to 0.75. The low efficiency samples mainly lie in the range 0.45 -- 0.68. The fitting trend line maintains an obvious positive slope, indicating that the benefit linkage has a stable direction in promoting the comprehensive effectiveness. This distribution result is consistent with the previous path estimation, which further indicates that the transparency of income return, the order redemption rate and the stability of guaranteed purchase are important factors affecting the performance of cooperatives to drive farmers.

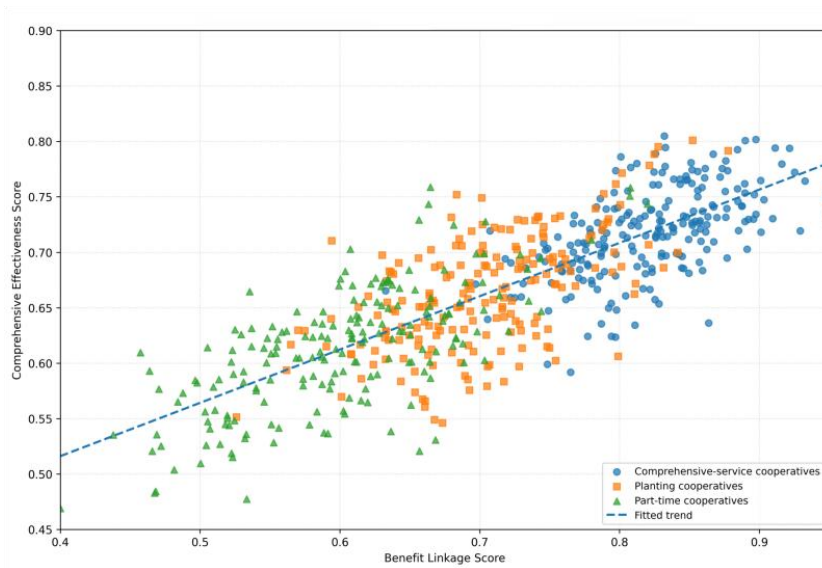


Figure 3: Scatter plot of benefit linkage and comprehensive effectiveness

To test the measurement stability of the observed variables, Fig. 4 shows the factor loading thermal distribution. The standardized loads of the 21 observed variables mainly fall in the range of 64.0%-86.0%, and the transparency of revenue return, order redemption rate, technical service arrival rate and participation persistence reach 86.0%, 83.0%, 81.0% and 79.0%, respectively. The average loads of the four dimensions of organization operation, service embedding, interest connection and participation response were 72.0%, 76.0%, 80.0% and 71.0%, respectively. The cross loads of dimensions not belonging to them are mostly lower than 30.0%, indicating that the measurement boundary is relatively clear.

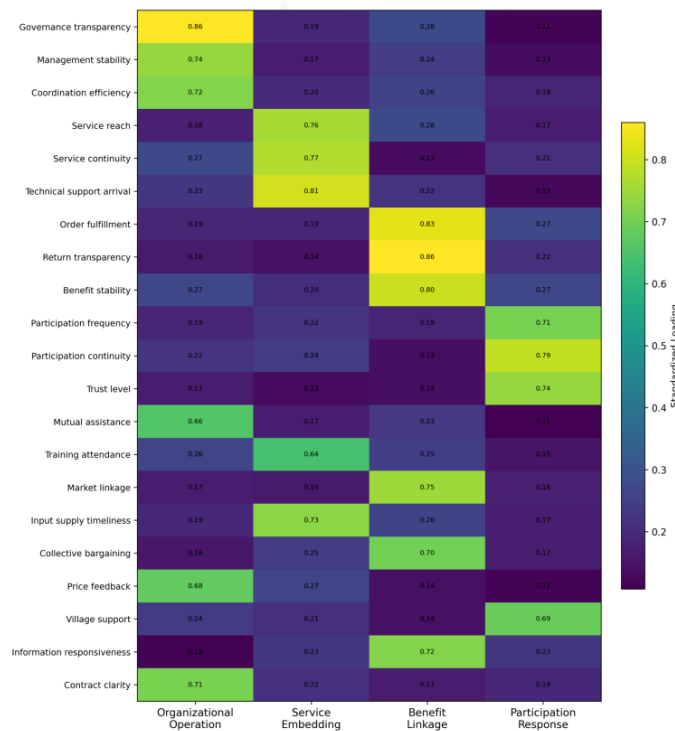


Figure 4: Normalized load thermal profile of observed variables

To observe the regional distribution differences, Fig. 5 shows the box plots of the comprehensive efficiency scores of the six cities in northern Anhui. The median values of the samples from Suzhou and Fuyang were 75.0% and 73.0%, respectively. Bozhou and Huaibei were 70.0% and 68.0%, respectively. Bengbu and Huainan were 66.0% and 65.0% respectively. The interquartile range of Suzhou and Fuyang was controlled at 8.0%-9.0%, and the internal samples were more concentrated. The interquartile range of Bengbu and Huainan expanded to 13.0%-14.0%, indicating that the difference in driving modes between regional cooperatives was more obvious. More than 80.0% of the samples are concentrated in cooperatives with clear income return and continuous service coverage.

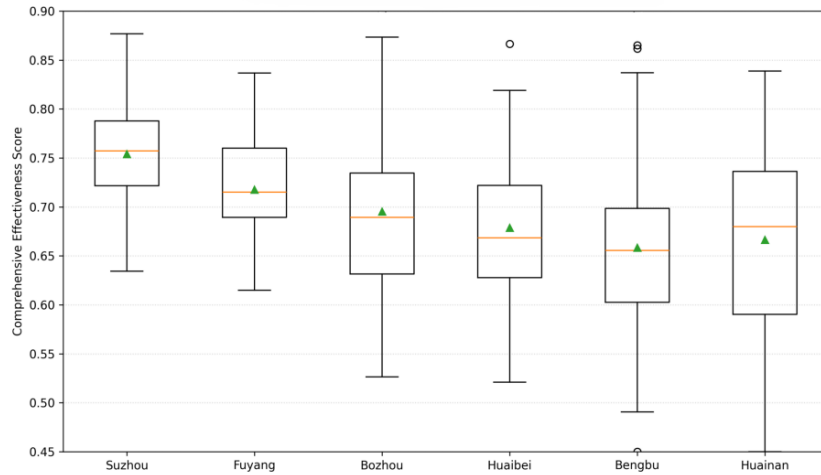


Figure 5: Box plot of the comprehensive effectiveness score of the six cities in northern Anhui

To test the robustness of the model under repeated sampling conditions, Fig. 6 illustrates the results of the kernel density superposition of the corrected composite score. 5000 Bootstrap results show that the main peak of each distribution is concentrated in the range of 69.0%-73.0%, and the maximum deviation of peak position is less than 2.0%. The mean value of the composite score was stable at about 71.0%, and the fluctuation range was about 4.3%. The samples are mainly concentrated in the range of 62.0%-78.0%, accounting for 74.8%, indicating that the model has good stability to sample disturbance.

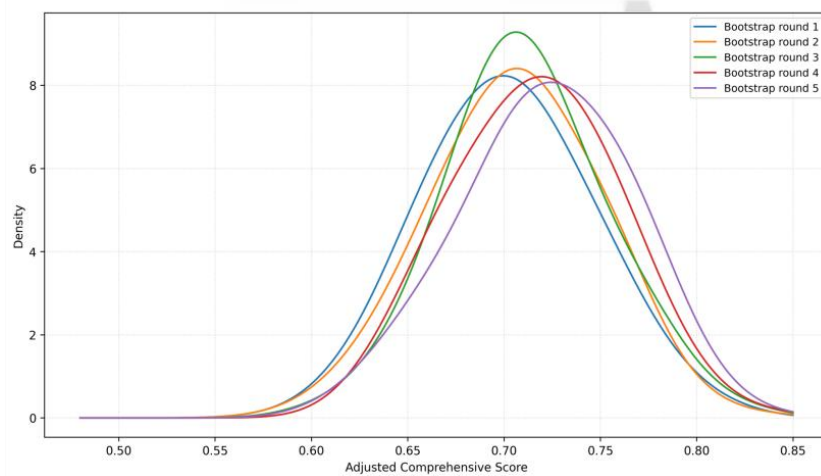


Figure 6: Superimposed plot of corrected integrated score kernel density

To illustrate the differences in output across cooperative types, Table 5 summarizes the evaluation results of plantation, part-time, and integrated service cooperatives. It can be seen that the comprehensive service cooperatives are at a high level in the three indicators of comprehensive effectiveness, interest connection and participation response, indicating that the service integration ability has an obvious supporting role in the performance of joint farmers and farmers.

Table 5: Comparison of evaluation outputs for different cooperative types

Cooperative Type	Mean Comprehensive Effectiveness	Mean Benefit-Linkage	Mean Participation Response	Stability
Planting Type	71.0%	74.0%	66.0%	90.0%
Part-Time Type	67.0%	69.0%	61.0%	89.0%
Integrated Service Type	76.0%	82.0%	72.0%	93.0%

To further present the internal structure of samples at different efficiency levels, radar comparison plots for the four latent variables are plotted in Fig. 7. The scores of high performance samples in the four dimensions of interest connection, service embedding, organization operation and participation response reached 84.0%, 81.0%, 78.0% and 76.0%, respectively. The medium efficiency samples correspond to 69.0%, 67.0%, 71.0% and 63.0%. The sample with low efficiency decreased to 53.0%, 52.0%, 61.0% and 49.0%. This difference shows that the main contraction points of the low-efficiency sample focus on the two dimensions of benefit linkage and participation response, while the advantage of the high-efficiency sample comes from the synchronous enhancement of service embedding and benefit transmission.

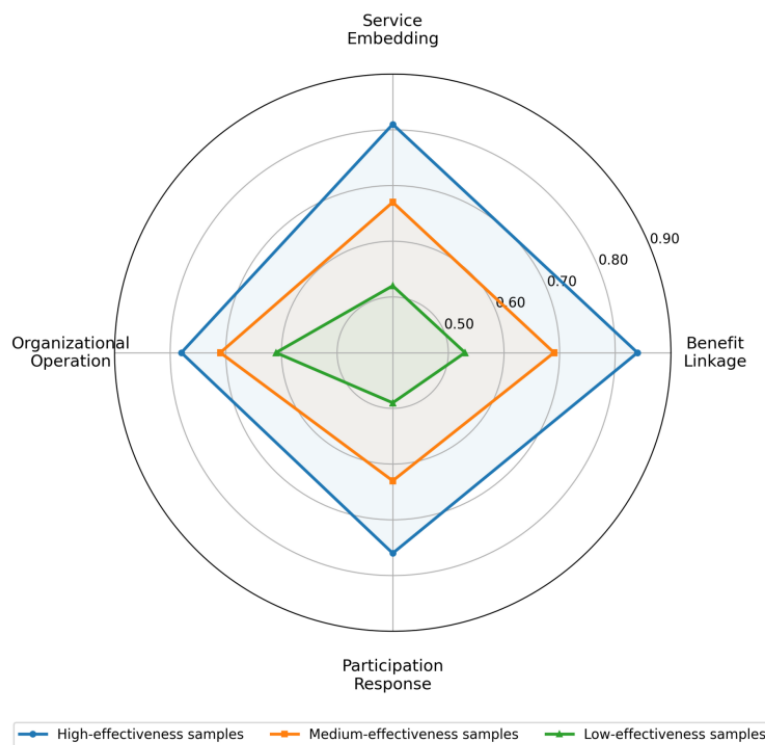


Figure 7: Comparison plot of sample latent variable radar for different effectiveness levels

To examine the contribution of the components of the model, Table 6 presents the ablation experiment results. The comprehensive explanatory degree of the complete model was 67.0%. After removing the service embedding coding module, it decreased to 59.0%. After removing the region correction term, it is 61.0%. After removing the path interaction term, it further decreased to 57.0%. It drops to 52.0% when only the base linear score is retained. The ablation results show that the three modules of variable coding, regional correction and path interaction have substantial contributions to the effectiveness evaluation of the joint agricultural belt and farm mechanism.

Table 6: Results of model ablation experiments

Model Setting	Overall Explanatory Power (R ²)	CFI	RMSEA
Full Model	67.0%	95.0%	3.9%
Without Service Embedding Encoding Module	59.0%	91.0%	5.1%
Without Regional Correction Term	61.0%	92.0%	4.8%
Without Path Interaction Term	57.0%	90.0%	5.4%
Baseline Linear Score Only	52.0%	88.0%	6.1%

In general, the structural equation model constructed in this paper maintains a high consistency among the measurement layer, the structure layer and the output layer. The loads of observed variables were mainly distributed in the range of 64.0%-86.0%, and the median comprehensive scores of regional samples were concentrated in the range of 65.0%-75.0%. After correction, the comprehensive scores maintained small fluctuations under repeated sampling conditions. The results show that the effectiveness of the mechanism is not determined by a single dimension, but a comprehensive result formed by the joint action of organization operation, service embedding, interest connection and farmer participation. Such a result structure provides a more stable data support for the mechanism explanation, regional comparison and governance direction of the subsequent discussion section.

4.3 Experimental Discussion

The experimental results show that the structural equation model constructed in this paper can describe the internal differences of the mechanism of agricultural cooperatives in northern Anhui. The observed variable loads are mainly distributed between 64.0% and 86.0%, indicating that the measurement layer has good aggregation performance. Fig. 3 shows that there is an obvious positive correlation between the level of benefit linkage and the comprehensive effectiveness, and the high-efficiency samples are more concentrated in the interval of higher benefit linkage. Fig. 5 shows that there are some differences in the median value of comprehensive effectiveness and the degree of dispersion in different city samples. Fig. 6, on the other hand, shows that the corrected comprehensive score fluctuates less under repeated sampling conditions, and the overall stability of the model is good. Table 5 further shows that comprehensive service cooperatives perform more prominently in terms of comprehensive effectiveness, interest linkage and participation response, indicating that there is a strong correspondence between service integration ability and the performance of joint farmers and farmers. The existing results can support region comparison and type recognition, but the application of the model still relies on relatively complete data records and relatively standardized field arrangement. For the samples with discontinuous accounts, more missing questionnaires or low informatization degree of cooperatives, the fineness of variable

expression will still be affected. Subsequent research can continue to introduce time series tracking, graph structure association, and finer-grained regional labels, so as to extend the evaluation of joint agricultural mechanism from static identification to dynamic comparison and annual review.

5 Conclusion

Focusing on the effectiveness evaluation task of the mechanism of agricultural cooperatives in North Anhui, this paper constructs a data analysis framework that integrates data extraction, variable coding, structural equation modeling and evaluation output. The framework organizes the cooperative operation accounts, farmer questionnaires, village-level statistical data and service records into a unified input matrix, and completes the expression of observed variables, the identification of latent variables, the estimation of structure and the comprehensive measurement in the same calculation chain. The empirical results show that organization operation, service embedding, interest connection and participation response jointly affect the effectiveness of the joint agricultural belt and farm mechanism, and there are clear hierarchical differences between different regions and different types of cooperatives. The model performs well in terms of observation load and repeated sampling stability, indicating that the combination of structural equation model and data coding strategy can describe the comprehensive performance of farmers driven by cooperatives more stably. Theoretically, this paper promotes the transformation of regional cooperative mechanism research from empirical judgment to computational expression. At the application level, this paper can provide a reviewable data basis for the classification and identification of cooperatives, the judgment of resource investment and the adjustment of rural revitalization policies in northern Anhui. However, there are still limitations in this paper. Firstly, the sample scope is concentrated in northern Anhui, and regional heterogeneity still has room for further expansion. Secondly, some variables still rely on the joint expression of questionnaires and ledgers, and the description of continuous time series behavior data is not sufficient. Subsequent studies can continue to incorporate time-series tracking, graph structure association, and cross-annual sample update mechanisms to enhance the adaptation ability of the model to regional heterogeneity and dynamic changes. At the same time, the multi-level evaluation results formed in this paper can trace back to specific dimensions and key indicators, making the evaluation conclusions interpretable, comparative and reviewable, and also providing quantitative support for county review, hierarchical governance and resource allocation.

Funding

This work was supported by the Suzhou University doctoral research launch project (2021BSK025). And Anhui Provincial Department of Education Humanities and Social Sciences Research Project, Youth Project, 2025AHGXSK40206.

References

- [1] Kolapo A, Didunyemi A J. Effects of exposure on adoption of agricultural smartphone apps among smallholder farmers in Southwest, Nigeria: implications on farm-level-efficiency[J]. *Agriculture & Food Security*, 2024, 13(1): 31.
- [2] Adereti D T, Gardezi M, Wang T, et al. Understanding farmers' engagement and barriers

- to machine learning-based intelligent agricultural decision support systems[J]. *Agronomy Journal*, 2024, 116(3): 1237-1249.
- [3] Uyar H, Karvelas I, Rizou S, et al. Data value creation in agriculture: A review[J]. *Computers and Electronics in Agriculture*, 2024, 227: 109602.
- [4] Dibbern T, Romani L A S, Massruhá S M F S. Main drivers and barriers to the adoption of Digital Agriculture technologies[J]. *Smart Agricultural Technology*, 2024, 8: 100459.
- [5] Sullivan C S, Gemtou M, Anastasiou E, et al. Building trust: A systematic review of the drivers and barriers of agricultural data sharing[J]. *Smart Agricultural Technology*, 2024, 8: 100477.
- [6] Chin S W, Rubambiza G, Zhao Y, et al. Realtime optimization and management system (ROAM): A decision support system for digital agriculture systems[J]. *Smart Agricultural Technology*, 2024, 8: 100452.
- [7] Lanucara S, Praticò S, Pioggia G, et al. Web-based spatial decision support system for precision agriculture: A tool for delineating dynamic management unit zones (MUZs)[J]. *Smart Agricultural Technology*, 2024, 8: 100444.
- [8] Hasan H R, Musamih A, Salah K, et al. Smart agriculture assurance: IoT and blockchain for trusted sustainable produce[J]. *Computers and Electronics in Agriculture*, 2024, 224: 109184.
- [9] Rizwan A, Khan A N, Ibrahim M, et al. Optimal environment control and fruits delivery tracking system using blockchain for greenhouse[J]. *Computers and Electronics in Agriculture*, 2024, 220: 108889.
- [10] Thomopoulos V, Tolis F, Blounas T F, et al. Application of Fuzzy logic and IoT in a small-scale Smart Greenhouse System[J]. *Smart Agricultural Technology*, 2024, 8: 100446.
- [11] Ayadi N Y, Bernard S, Bossy R, et al. A unified approach to publish semantic annotations of agricultural documents as knowledge graphs[J]. *Smart Agricultural Technology*, 2024, 8: 100484.
- [12] Bandaru L, Irigireddy B C, Davis B. DeepQC: A deep learning system for automatic quality control of in-situ soil moisture sensor time series data[J]. *Smart Agricultural Technology*, 2024, 8: 100514.
- [13] Shahab H, Iqbal M, Sohaib A, et al. Design and implementation of an IoT-based monitoring system for early detection of lumpy skin disease in cattle[J]. *Smart Agricultural Technology*, 2024, 9: 100609.
- [14] Goldenits G, Mallinger K, Raubitzek S, et al. Current applications and potential future directions of reinforcement learning-based Digital Twins in agriculture[J]. *Smart Agricultural Technology*, 2024, 8: 100512.
- [15] Liu G, Zhong K, Li H, et al. A state of art review on time series forecasting with machine learning for environmental parameters in agricultural greenhouses[J]. *Information Processing in Agriculture*, 2024, 11(2): 143-162.

- [16] Peng X, Zhao Z, Wang X, et al. A review on blockchain smart contracts in the agri-food industry: Current state, application challenges and future trends[J]. *Computers and Electronics in Agriculture*, 2023, 208: 107776.
- [17] Chen H Y, Sharma K, Sharma C, et al. Integrating explainable artificial intelligence and blockchain to smart agriculture: Research prospects for decision making and improved security[J]. *Smart agricultural technology*, 2023, 6: 100350.
- [18] de Andrade Porto J V, Dorsa A C, de Moraes Weber V A, et al. Usage of few-shot learning and meta-learning in agriculture: A literature review[J]. *Smart Agricultural Technology*, 2023, 5: 100307.
- [19] Gebresenbet G, Bosona T, Patterson D, et al. A concept for application of integrated digital technologies to enhance future smart agricultural systems[J]. *Smart agricultural technology*, 2023, 5: 100255.
- [20] Hafeez A, Husain M A, Singh S P, et al. Implementation of drone technology for farm monitoring & pesticide spraying: A review[J]. *Information processing in Agriculture*, 2023, 10(2): 192-203.
- [21] Chen X, Jiang Z, Yang J, et al. Data-driven decision support scheme for multi-area light environment control in greenhouse[J]. *Computers and Electronics in Agriculture*, 2023, 211: 108033.