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EQUITY INCENTIVE MECHANISM FOR AN ALLIANCE-BASED AGRICULTURAL PRODUCT LOGISTICS MODEL UNDER DIGITAL-INTELLIGENCE PLATFORMS

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Annotation. In China, agricultural logistics systems are still confronted with persistent challenges, including excessive circulation links, high post-harvest losses, and elevated transaction costs. As a result, market mismatches characterized by unsold produce and difficulties in procurement are frequently observed. Increasing attention has therefore been drawn from policymakers, industry practitioners, and academic researchers. Existing studies are primarily focused on infrastructure investment, information system development, and the optimization of individual logistics models. However, systematic investigations into multi-agent collaborative governance and stable incentive mechanisms under digital-intelligence platforms remain scarce. To address this gap, a conceptual framework for an alliance-based hybrid agricultural logistics model was constructed by synthesizing China's logistics practices with international experience. Within a multi-principal–multi-agent theoretical framework, a supply chain consisting of agricultural suppliers, digital platform enterprises, and third-party logistics providers was examined. An equity incentive mechanism was introduced to analyze participants' effort levels, payoff structures, and cooperation stability. Simulation results demonstrate that the lead agent's additional returns increase significantly as the equity share rises, accompanied by enhanced effort provision. The lead principal's logistics expenditures decrease with higher equity allocation, while the payoffs of subordinate principals and agents remain largely stable. A Pareto-improving outcome is thus generated for all supply chain participants. The findings offer a novel theoretical explanation for the recurring problem of unsold agricultural products and provide valuable managerial insights for the design of logistics structures and incentive mechanisms in digital-intelligence platform environments.

Keywords: agricultural logistics; logistics models; digital-intelligence platforms; incentive mechanisms.

JEL classification: L11, L42, M11.

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Introduction

In recent years, with the continuous advancement of agricultural modernization and the implementation of China's Digital China strategy, inefficiencies in agricultural product circulation have become increasingly prominent. As a foundational sector of the national economy, agriculture is widely recognized as playing an irreplaceable role in safeguarding food security. It also plays a critical role in promoting sustained income growth for farmers and advancing the rural revitalization strategy. China is regarded as one of the world's largest agricultural producers. High output levels of staple grains, vegetables, fruits, and livestock products have been consistently maintained. For example, in 2012, China's total grain output was recorded at 589.58 million tons. During the same year, fruit production reached 240.57 million tons.

However, despite continuous improvements in production capacity, synchronous upgrading of the agricultural circulation system has not been achieved. The logistics sector continues to be affected by prolonged circulation chains, high post-harvest losses, elevated transaction costs, and severe information asymmetry. As a result, market mismatches are frequently observed. Such mismatches include difficulties in selling and purchasing agricultural products and increased output without corresponding income growth. High-quality agricultural development is therefore seriously constrained. A critical question is consequently raised: Why do unsold produce and sharp price fluctuations persist during the circulation stage despite expanding supply capacity and rising urban–rural consumption demand? Such a contradiction warrants in-depth investigation.

In recent years, profound changes have been experienced in China's agricultural circulation environment. On the one hand, digital technologies have been rapidly integrated into the agricultural sector. Emerging technologies, including big data, the Internet of Things, and blockchain, have been continuously applied to production, circulation, and trading processes. Agricultural supply chains are thus being driven toward digital-intelligent, platform-based, and networked development. On the other hand, steady progress has been made in cold-chain logistics technologies. Consumption structures have also been upgraded. Significantly higher expectations have been expressed by consumers regarding product quality and safety. In addition, greater demands have been placed on traceability transparency and delivery timeliness. Under such conditions, traditional circulation models centered on wholesale markets are increasingly unable to meet evolving market demands. Agricultural products are characterized by perishability, strong seasonality, and substantial price volatility. Stringent requirements are therefore imposed on logistics system professionalism, organizational coordination capacity, and risk management mechanisms. Sole reliance on conventional logistics systems is insufficient to satisfy the needs of modern agricultural circulation.

To address these challenges, the Chinese government has placed strong emphasis on improving the agricultural circulation system. A series of policy initiatives have been introduced, including green logistics channels for agricultural products and the promotion of direct procurement between farms and supermarkets. The 2013 Central Government No. 1 Document explicitly called for the enhancement of circulation efficiency. The cultivation of modern circulation formats and emerging business models was also emphasized. In recent years, policy priorities have been further shifted toward digital villages, smart agriculture, and agricultural digital transformation. Strategic guidance has thus been provided for the digital-intelligent upgrading of agricultural circulation systems. In practice, the levels of digitalization and intelligence in China's agricultural logistics system remain inadequate. Weak cold-chain infrastructure continues to exist. Low organizational integration among market participants is also observed. In addition, effective multi-agent coordination mechanisms are largely absent. The full realization of policy benefits is constrained.

Against the backdrop of the rapid expansion of the digital platform economy, an increasing volume of agricultural products is being traded and distributed through e-commerce platforms, supply chain platforms, and smart logistics systems. As a result, a platform-based hybrid circulation model integrating online and offline channels has gradually taken shape. Collaboration among logistics participants has become increasingly complex. Suppliers, platform enterprises, and logistics service providers are embedded in multi-layered principal–agent relationships. In such an environment, benefit allocation and incentive mechanisms have emerged as critical determinants of system stability. Promoting multi-agent collaborative governance and long-term stable cooperation under digital-intelligence platform environments through appropriate organizational design and incentive arrangements has therefore become a pressing theoretical and practical issue.

Accordingly, agricultural logistics supply chains under digital-intelligence platforms are taken as the research focus. An alliance-based hybrid logistics model is constructed. Within a multi-principal–multi-agent theoretical framework, an equity incentive mechanism is introduced. Participants' behavioral decisions, effort levels, and payoff structures are systematically examined. In addition, the influence of incentive mechanisms on supply chain stability is analyzed. Overall supply chain efficiency is also evaluated. The analysis aims to provide theoretical support for the digital-intelligent transformation of China's agricultural logistics systems. Policy implications for collaborative governance are further derived.

1. Literature Review

Foreign scholars have paid early attention to agricultural logistics and supply chain coordination. Relevant studies have gradually evolved from conceptual definitions and functional analyses. Subsequent research has focused on distribution system optimization, information system applications, and supply chain collaboration. With the development of operations research, information technologies, and the digital platform economy, research emphasis has progressively shifted. Optimization of individual logistics links has been deemphasized. Greater attention has been directed toward multi-agent coordination mechanisms and system integration efficiency. Through model construction and empirical analysis, theoretical support has been provided for complex supply chain governance. Ahumada and Villalobos (2009) systematically reviewed modeling approaches for fresh agricultural product supply chains. Logistics coordination and information sharing were identified as key determinants in reducing post-harvest losses. Mena *et al.* (2010) further demonstrated the role of organizational integration from a supply chain coordination perspective. They found that organizational integration exert a significantly stronger impact on logistics performance than technological investment alone.

In developed countries such as the United States and the Netherlands, relatively mature standardized operating frameworks have been established for agricultural supply chains supported by digital platforms and intelligent logistics systems. Hübner *et al.* (2016) found that fulfillment efficiency is significantly improved under an online order-driven "front warehouse plus cold-chain distribution" model. Bourlakis *et al.* (2014) provided empirical evidence from the UK retail market. Substantial reductions in fresh product losses were observed following investment in cold-chain infrastructure. Consumer satisfaction was also found to be enhanced. By contrast, research on agricultural logistics in China was initiated at a relatively late stage. Early studies were primarily devoted to problem diagnosis. In recent years, scholarly attention has been gradually shifted toward digital-intelligent transformation and platform governance mechanisms.

The first stream of research has mainly examined the constraints underlying low logistics efficiency. Fragmented small-scale production, information asymmetry, and asset specificity are generally regarded by international scholars as fundamental sources of inefficiency in agricultural logistics. From a transaction cost perspective, Hobbs (1996) pointed out that high asset specificity is associated with a higher likelihood of opportunistic behavior in logistics transactions. In developing-country contexts, Reardon *et al.* (2012) found that fragmented smallholder production structures hinder the realization of economies of scale. Persistently high logistics costs were therefore identified as a structural outcome. Based on empirical evidence from India, Nakandala *et al.* (2017) showed that incentives for cold-chain investment are significantly constrained by insufficient organizational integration. Govindan *et al.* (2014) further argued that information asymmetry and demand uncertainty constitute major drivers of inventory accumulation and product losses. In the Chinese context, Wang *et al.* (2021) demonstrated that logistics efficiency is significantly affected by the degree of coordination among supply chain participants. A high degree of consistency with international findings was observed. Collectively, these studies reveal deep-rooted causes of low logistics efficiency from the perspectives of organizational structure, transaction mechanisms, and information environments.

The second stream of research has focused on solution pathways and model innovation. International scholars have proposed systematic optimization strategies from a supply chain integration perspective. *Christopher* (2016) emphasized that transaction costs can be significantly reduced through supply chain integration. Supply chain responsiveness was also found to be improved. On the basis of blockchain and Internet of Things technologies, Kamble *et al.* (2020) demonstrated that digitalization markedly enhances cold-chain transparency and credibility. Gorwa (2019) found that last-mile delivery efficiency is improved through platform-led logistics alliances. In China, research orientation has likewise been shifted from single-mode optimization toward platform-based coordination mechanisms. Zhou *et al.* (2019) argued that hybrid logistics models involving multi-agent collaboration outperform single third-party logistics models. Liang *et al*. (2026) provided empirical evidence. The degree of coordination among platforms, logistics enterprises, and suppliers was shown to directly affect consumer satisfaction. Collectively, these studies confirm the critical role played by digital-intelligent coordination in improving agricultural logistics efficiency.

As digital platforms have become deeply embedded in agricultural circulation systems, incentive mechanisms have begun to be examined from a governance design perspective. Kapacinskaite and Mostajabi (2024) found that platform governance mechanisms exert significant disciplinary effects on service providers' behavior. Zhang *et al.* (2024) demonstrated that system efficiency is most effectively enhanced through a combined mechanism of equity incentives and performance-based contracts. In contrast to industrial products, agricultural products are characterized by high perishability. Stricter requirements are therefore imposed on logistics timeliness and stability. Akkerman *et al.* (2010) pointed out that fresh product supply chains exhibit high sensitivity to response speed. Using data from China's fresh food platforms, Mustafa *et al.* (2024) found that platform repurchase rates are directly affected by cold-chain fulfillment capability. Overall, information transparency is facilitated by the development of digital platforms. Industrial coordination is strengthened. Resource allocation efficiency is improved. Price discovery functions are also supported (Akıl *et al*., 2022; Lin *et al*., 2016). However, owing to perishability and high asset specificity, agricultural e-commerce logistics remain predominantly dependent on short-distance third-party transportation. Specialization levels are insufficient (Zhou *et al*., 2024; Ai, 2025), and multi-agent collaborative governance and stable incentive mechanisms remain underdeveloped. Overall system efficiency is therefore constrained.

In sum, although agricultural logistics systems have been examined from perspectives including technological empowerment, model innovation, and performance improvement, several limitations remain. First, most studies have been conducted from single-technology or single-actor perspectives. A systematic examination of operational mechanisms in online–offline integrated logistics systems led by digital platforms is lacking. Second, methodological approaches are predominantly empirical and descriptive. Rigorous game-theoretic modeling remains insufficient for capturing strategic interactions among platforms, suppliers, and logistics enterprises. Third, cooperative relationships are often assumed to be exogenously stable. Coordination instability arising from heterogeneous objectives among participants is largely neglected. Fourth, research on incentive mechanisms has been mainly concentrated on price contracts and performance assessments. Limited attention has been devoted to the governance effects of equity incentives in platform-based logistics alliances.

On the basis of the above analysis, a digital platform-led agricultural logistics alliance supply chain is adopted as the research context. Against the backdrop of the rapidly expanding platform economy, incentive mechanisms under hybrid agricultural logistics models are investigated. Several research questions are addressed. How are optimal decisions made by participants under digital-intelligent hybrid logistics systems? How are members' effort levels and payoff distributions affected by equity incentives? Can optimal strategies be aligned across participants? If alignment cannot be achieved, how can coordination and incentive compatibility be realized through institutional design?

The remainder of the study is organized as follows. In Section 3, the alliance-based hybrid agricultural logistics model and associated operational mechanisms are introduced. In Section 4, a multi-principal–multi-agent model is constructed. Equity incentive contracts are designed. Model solutions are subsequently derived. In Section 5, numerical analyses are conducted to examine variations in participants' effort levels and payoffs under different equity ratios. In Section 6, the study is concluded. Policy implications are presented, and directions for future research are outlined.

2. Methodology

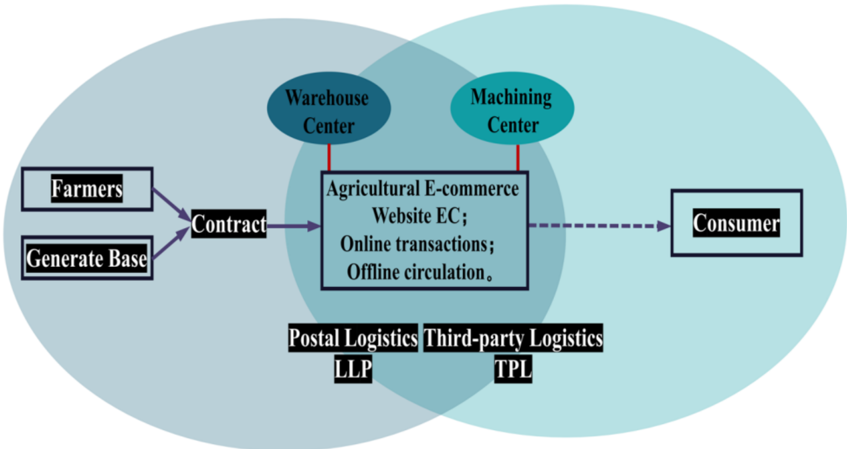
2.1 Problem Description

With the rapid development of digital technologies, platform economies, and intelligent logistics systems, agricultural product circulation has been gradually transformed. A shift has occurred from traditional offline channels toward digitally empowered hybrid logistics models integrating online and offline operations. At present, two typical forms are observed during this transition, namely, C2C and B2C models (Zheng *et al.*, 2023; Li *et al.*, 2023). Although the C2C model offers certain advantages in transaction costs and market entry barriers, effective quality control is difficult to ensure. Trading entities are highly fragmented, and platform supervision remains weak. Under China's smallholder-based agricultural production structure, output is dispersed and standardization levels are low. Robust quality traceability and accountability mechanisms are often absent, so food safety risks are likely to arise. Consumer trust is consequently undermined (Mayayise, 2024). Accordingly, a platform-led B2C hybrid logistics model for agricultural products is adopted as the research focus.

Compared with supermarket-dominated logistics systems, the B2C hybrid model offers advantages in reducing circulation links. Intermediate logistics costs are lowered, and delivery efficiency is improved. Effective quality supervision is also facilitated. However, supermarket-based models heavily depend on physical outlets. Site selection, sorting, shelving, and store management are required, so operating costs are substantially increased. By contrast, direct shipment from nearby warehouses is enabled by the alliance-based hybrid logistics model after customer orders are placed. Store management processes are bypassed. Cost savings are thus realized by upstream and downstream supply chain participants.

Regarding the selection of logistics service providers, third-party logistics services are considered appropriate. This suitability is attributed to the low level of organization in China's agricultural logistics sector and the geographically dispersed distribution of consumers. Among available providers, nationwide network coverage and a well-established delivery system are possessed by postal logistics, so remote areas can be reached. However, operational efficiency remains relatively low. By contrast, higher efficiency and faster delivery are offered by commercial courier companies, including STO, YTO, ZTO, and Yunda. Coverage gaps are still present, rendering nationwide service difficult. Consequently, a leadership logistics partner model dominated by postal logistics and integrating social courier resources is identified as the optimal organizational form under an alliance-based hybrid logistics framework. The leadership logistics partner (LLP) model is thus adopted.

Under a digitally enabled hybrid logistics model, supply chain participants are defined to include the agricultural product supplier (S), platform operator (EC), two third-party logistics providers, and end consumers. The two third-party logistics providers consist of TPL1, representing postal logistics, and TPL2, representing commercial courier firms. *Figure 1* illustrates the specific operational process. The digital agricultural circulation model has emerged in response to the convergence of socioeconomic development and information technologies. Preliminary scale has been achieved by platforms such as Yihaodian Fresh and SF Fresh. However, operational performance remains below expectations, and loose cooperation among supply chain partners is observed. Professional logistics systems are still underdeveloped, and regulatory mechanisms are imperfect. The hybrid logistics model proposed in the present study is designed to address these shortcomings. A future direction for agricultural logistics development is represented. Within this framework, postal logistics is positioned as the leadership logistics partner. Extensive network coverage and a continuously optimized distribution system are leveraged, so partner logistics providers are supervised more effectively. More professional and efficient delivery of agricultural products is consequently enabled.



Source: created by the authors.

Figure 1. **Schematic of the Hybrid Agricultural Product Logistics Model**

Through detailed calculations, Zhou et al. (Zhou *et al.*, 2011) demonstrated the supply logistics LLP model to be more effective than the direct outsourcing model. However, potential moral hazard issues under the LLP framework were not considered. As the leading logistics partner, postal logistics may exhibit opportunistic behavior. Insufficient supervision of TPL2 may occur, and effort levels may be reduced. Overall supply chain efficiency can therefore be undermined, and the long-term sustainability of the LLP model may be threatened. In response to this limitation, an equity incentive mechanism is introduced in the present study. Changes in profit distribution among supply chain participants after the introduction of equity incentives are examined. The feasibility of equity incentives in enhancing overall system efficiency is also evaluated.

In the current digitalized agricultural circulation system, platform-driven fresh product logistics services, such as Yihaodian Fresh and SF Fresh, have begun to take shape. However, operational performance remains unsatisfactory, and loose supply chain coordination is observed. Professional logistics capabilities are insufficient, along with regulatory mechanisms. An alliance-based hybrid logistics model is proposed in the present study. Intelligent warehousing and distribution systems are integrated with digital information platforms to address the aforementioned challenges. Cost optimization is enabled, delivery efficiency is improved, and quality supervision is strengthened.

Under the proposed model, postal logistics is positioned as the leading logistics partner. Extensive nationwide network coverage and a continuously optimized distribution system are leveraged. Real-time supervision of other third-party logistics providers is conducted, and collaborative guidance is provided. Professional and efficient operation of the agricultural supply chain is thereby ensured. Moreover, a solid foundation for supply chain stability is established, and mutually beneficial cooperation among multiple stakeholders is facilitated.

2.2 Variable Description

According to the preceding discussion, participants involved in logistics activities under the "brick-and-click" agricultural logistics model are identified. These participants include the agricultural product supplier (S), the platform-based circulation service provider (EC), and two third-party logistics service providers, denoted as TPL1 and TPL2. A multi-principal–multi-agent relationship is thereby formed. As the dominant party, the EC possesses significant channel advantages and strong financial and technological capabilities. Outsourcing cooperation contracts with third-party logistics providers are therefore signed. Under the established framework, effort levels of the third-party logistics providers are inferred by S and EC based on respective observations. *Table 1* provides the definitions of the relevant variables.

Table 1. Definition of variables

Variable	Definition
EC	Principal
S	Secondary principal
TPL1	Primary agent
TPL2	Secondary agent
e_i	Effort level of TPLi (i=1, 2)
c (e_i)	Cost of effort, $e_i \in E_i$
E_i	Feasible effort set of TPLi
x_k	Observation of EC under effort level e_i
$\tilde{x}_k$	Observation of S under effort level e_i
$\tilde{p}_k(e_1, e_2)$	For (e_1, e_2), the probability that S observes the outcome
$p_k(e_1, e_2)$	For (e_1, e_2), the probability that EC observes the result x_k
$V(x)$	Utility of EC
U^i	Utility of TPLi ($U^i \geq 0$) satisfies $U^i(w+\tilde{w}) = U^i(w) + U^i(\tilde{w})$
$\underline{U}^i$	Residual utility of providing logistics services

Note: All participants are assumed to be risk neutral.

Source: created by the authors.

2.3 Model Construction

2.3.1 Cost Integration Model under the LLP Model

The total logistics remuneration paid by EC to the LLP is denoted as $z+\tilde{z}$. The payment made by the LLP to TPL2 is denoted as $\tilde{w}^2 = w(\tilde{x}^2)$. The monitoring cost incurred by EC for supervising the LLP is denoted as M^1. The monitoring cost incurred by the LLP for supervising TPL2 is denoted as M^L. In addition, an extra payment M^2 is provided by EC to the LLP as compensation for monitoring effort. As a logistics enterprise, the LLP is characterized by advantages in professional specialization and possesses superior knowledge of TPL2. To ensure willingness to engage in supervision, the monitoring cost incurred by the LLP for supervising TPL2 must be lower than the monitoring cost incurred by EC. Accordingly, the assumption $M^L \le M^2$ is indicated as reasonable. The contract between the LLP and EC is specified by the following functions:

$$\max \sum P_k(e_1,e_2)V(x_k - z(x_k)) + \sum \tilde{P}_k(e_1,e_2)V(\tilde{x}_k - z(\tilde{x}_k)) - M^1 - M^2, \tag{1}$$

$$\begin{aligned}\text{S.t.} &\sum P_k(e_1,e_2)\mathrm{U}(\mathrm{z} - w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) \\ &-c(e_1) - M^L + M^2 \ge \underline{U}^1,\end{aligned} \tag{2}$$

where e_1, e_2, and w^2 are determined by the objective function specified in the contract between the LLP and TPL2:

$$\begin{aligned}\max &\sum P_k(e_1,e_2)\mathrm{U}(\mathrm{z} - w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) \\ &-c(e_1) - M^L + M^2,\end{aligned} \tag{3}$$

$$\text{S.t.} \sum P_k(e_1,e_2)\mathrm{U}(w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(w^2(\tilde{x}_k)) - c(e_2) \ge \underline{U}^2, \tag{4}$$

$$e_1 \in \arg\max_a \left\{\sum P_k(a,e_2)\mathrm{U}(z - w^2(x_k)) + \sum \tilde{P}_k(a,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) - c(a)\right\}, \tag{5}$$

$$e_2 \in \arg\max_a \left\{\sum P_k(e_1,a)\mathrm{U}(w^2(x_k)) + \sum \tilde{P}_k(e_1,a)U(w^2(\tilde{x}_k)) - c(a)\right\}. \tag{6}$$

2.3.2 Cost Integration Model under the LLP Model

Existing studies indicate that consumers' perceptions of product quality in digitally enabled agricultural logistics environments are shaped by multiple factors. Intrinsic product attributes and service levels are relevant determinants. The timeliness, stability, and traceability of the logistics process are also closely associated with quality perception. However, in contrast to traditional platform firms that mainly rely on self-operated logistics or a single third-party logistics model, agricultural product distribution under hybrid logistics structures is subject to various practical constraints. Complex road conditions are frequently encountered, delivery chains are often extended, and stringent cold-chain control requirements are imposed. Under such conditions, multi-scenario distribution demands cannot be effectively addressed by a single logistics organization. Delivery efficiency is therefore likely to be reduced, and cargo loss rates may increase. Fulfillment failures may also occur (Xu *et al.*, 2014). For fresh agricultural product enterprises characterized by high homogeneity and strong perishability, rational selection of logistics modes is of critical importance. Product quality can be ensured through appropriate logistics arrangements. Consumer satisfaction can also be effectively enhanced (Zhang *et al.*, 2011).

As logistics efficiency has gradually become a core competitive factor in digitally enabled agricultural circulation systems, a key research issue has been raised. Endogenous motivation of third-party logistics service providers needs to be demonstrated through appropriate institutional design. A strong sense of responsibility and collaboration is also required to improve overall supply chain performance. Accordingly, the introduction of equity incentive mechanisms is regarded as a feasible approach. Interest alignment and incentive constraints can be established through such mechanisms, and effort levels of logistics providers can be enhanced. Cooperation stability can also be strengthened, thereby contributing to efficient supply chain operations (Chen *et al.*, 2025; Zeng *et al.*, 2023). To avoid infringement upon existing interests under the hybrid model, the equilibrium solution of the equity structure r should be carefully determined. The determination is based on the additional monitoring fee originally paid by EC to TPL2 under the LLP framework. The fixed payment M^2 is thus converted into an equity-based incentive. Under the "brick-and-click" agricultural logistics model, full ownership is initially held by the dominant party, EC, which possesses strong scale advantages and financial capability. A proportion ($0 < r < 1$) of equity is subsequently transferred to the LLP. The additional monitoring cost M^2 is no longer paid. The expected monitoring cost incurred by the LLP for supervising TPL2 is denoted as M^L, and the actual monitoring cost is denoted as M'. The condition $M^L \le M'$ is assumed because equity participation induces much supervisory effort. Accordingly, the payoff of the LLP is composed of two components; contractual remuneration and equity returns are included.

The contract between the LLP and EC is specified by the following functions:

$$\max \sum P_k(e_1,e_2)V(x_k - z(x_k))(1-r) + \sum \tilde{P}_k(e_1,e_2)V(\tilde{x}_k - z(\tilde{x}_k)) - M^1, \tag{7}$$

$$\text{S.t.} \sum P_k(e_1,e_2)\mathrm{U}(\mathrm{z} - w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) - c(e_1) - M' \ge \underline{U}^1, \tag{8}$$

where e_1, e_2, and w^2 are determined by the objective function specified in the contract between the LLP and TPL2:

$$\begin{aligned}\max & \sum P_k(e_1,e_2)\mathrm{U}(\mathrm{z} - w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) \\ & + r\sum P_k(e_1,e_2)\mathrm{V}(x_k - z(x_k)) - c(e_1) - M',\end{aligned} \tag{9}$$

$$\text{S.t.} \sum P_k(e_1,e_2)\mathrm{U}(w^2(x_k)) + \sum \tilde{P}_k(e_1,e_2)U(w^2(\tilde{x}_k)) - c(e_2) \ge \underline{U}^2, \tag{10}$$

$$e_1 \in \arg\max_a \left\{ \begin{aligned} & \sum P_k(a,e_2)\mathrm{U}(z - w^2(x_k)) + \sum \tilde{P}_k(a,e_2)U(\tilde{z} - w^2(\tilde{x}_k)) + \\ & r\sum P_k(a,e_2)\mathrm{V}(x_k - z(x_k)) - c(a) \end{aligned} \right\}, \tag{11}$$

$$e_2 \in \arg\max_a \left\{ \sum P_k(e_1,a)\mathrm{U}(w^2(x_k)) + \sum \tilde{P}_k(e_1,a)U(w^2(\tilde{x}_k)) - c(a) \right\}. \tag{12}$$

3. Results Analysis

3.1 Cost–benefit Analysis

Under both scenarios, effort levels of the LLP and TPL2 are denoted as (e_1, e_2). The utility function of EC is defined as $V(x) = x$. According to (Zhang *et al*., 2011), under the LLP mode, fixed compensation received by TPL1 as the leadership logistics partner is given by Equation (13). The fixed payment obtained by TPL2 is determined by Equation (14). Consistent with the direct outsourcing mode, only reservation utilities are received by the two logistics agents. The reservation utility of TPL1 is denoted as $\underline{U}^1$, and the reservation utility of TPL2 is denoted as $\underline{U}^2$. Total remuneration is equally shared between S and EC. The transfer payment from S and the direct payment made by EC are determined by Equation (15). Under the leadership logistics partner mode, a reduction in supervision cost incurred by EC can be observed. However, the LLP do not obtain additional benefits from professional specialization. Such an outcome is caused by profit squeezing by other supply chain members, which consequently reduces the willingness of the LLP to participate in cooperation. Long-term and stable partnerships among upstream firms, downstream firms, and the LLP are therefore difficult to establish.

$$U^{-1}(c(\hat{e}^1)+\underline{U}^1+M^L-M^2), \tag{13}$$

$$U^{-1}(c(\hat{e}^2)+\underline{U}^2), \tag{14}$$

$$\tfrac{1}{2}U^{-1}(c(\hat{e}^1)+\underline{U}^1+M^L-M^2)+\tfrac{1}{2}U^{-1}(c(\hat{e}^2)+\underline{U}^2). \tag{15}$$

After the introduction of equity incentives, the objective function is solved. The participation constraint for agents is retained, and the incentive compatibility constraint is omitted. A Lagrange function is then constructed.

$$\begin{aligned} L=&\sum P_k(e_1,e_2)V(x_k-z(x_k))(1-r)+\sum \tilde{P}_k(e_1,e_2)V(\tilde{x}_k-z(\tilde{x}_k))-M^1 \\ &+\lambda(\sum P_k(e_1,e_2)U(z-w^2(x_k)) \\ &+\sum \tilde{P}_k(e_1,e_2)U(\tilde{z}-w^2(\tilde{x}_k))-c(e_1)-M^{'}-\underline{U}^1), \end{aligned} \tag{16}$$

By applying the Kuhn–Tucker conditions, the solution is obtained as follows:

$$U^{'}(z-w^2(x_k))=\frac{1-r}{\lambda},U^{'}(\tilde{z}-w^2(\tilde{x}_k))=\frac{1}{\lambda}, \tag{17}$$

When $r = 0$,

$$U^{'}(z-w^2(x_k))=U^{'}(\tilde{z}-w^2(\tilde{x}_k))=\frac{1}{\lambda}. \tag{18}$$

At this point, $z-w^2(x_k)=\tilde{z}-\tilde{w}^2(x_k)$, and both are constants, representing the scenario without equity incentives. Solving for $\partial L/\partial\lambda=0$ yields:

$$z+\tilde{z}-w^2-\tilde{w}^2=U^{-1}(c(\hat{e}^1)+\underline{U}^1+M^{'}). \tag{19}$$

Similarly, solving the objective function when the LLP contracts with TPL2 yields:

Conclusion 1: An identical marginal rate of substitution is held by the principal and the agent under different income states.

Proof: As above, construct the Lagrange function:

$$\begin{aligned}L^{'}=&\sum P_k(e_1,e_2)U(z-w^2(x_k))+\sum \tilde{P}_k(e_1,e_2)U(\tilde{z}-w^2(\tilde{x}_k))\\&+r\sum P_k(e_1,e_2)V(x_k-z(x_k))-c(e_1)-M^{'}\\&+\lambda^{'}(\sum P_k(\hat{e}_1,\hat{e}_2)U(w^2(x_k))+\sum \tilde{P}_k(\hat{e}_1,\hat{e}_2)U(w^2(\tilde{x}_k))-c(e_2)-\underline{U}^2),\end{aligned} \tag{20}$$

Using the Kuhn–Tucker condition yields:

$$\frac{U^{'}(z-w^2(x_k))}{U^{'}(w^2(x_k))}=\frac{U^{'}(\tilde{z}-w^2(\tilde{x}_k))}{U^{'}(w^2(\tilde{x}_k))}=\lambda^{'}. \tag{21}$$

The ratio of marginal utility to income is required to remain constant for the principal and agent. Independence from output levels is also required. By rearranging the above conditions, Equation (22) is obtained. Under different income states, identical marginal rates of substitution are maintained by both parties. The conditions of Pareto optimality are therefore satisfied.

$$\frac{U^{'}(z-w^2(x_k))}{U^{'}(\tilde{z}-w^2(\tilde{x}_k))}=\frac{U^{'}(w^2(x_k))}{U^{'}(w^2(\tilde{x}_k))}. \tag{22}$$

Conclusion 2: $w^2+\tilde{w}^2=U^{-1}(c(\hat{e}^2)+\underline{U}^2)$; the utility of TPL2 is $\underline{U}^2$.

Due to the following equation:

$$\frac{\partial L^{'}}{\partial \lambda^{'}}=0\rightarrow U(w^2+\tilde{w}^2)=c(\hat{e}^2)+\underline{U}^2, \tag{23}$$

By combining the above analysis, the remuneration $z+\tilde{z}=U^{-1}(c(\hat{e}^1)+\underline{U}^1+M^{'})+U^{-1}(c(\hat{e}^2)+\underline{U}^2)$ received by the LLP can be obtained. By substituting the remuneration into Equation (8), a reservation utility $\underline{U}^1$ from logistics services is obtained by the LLP. After the incorporation of equity incentives, the final utility of the LLP becomes $\underline{U}^1+r(x_k-z)$. Under the LLP mode with the introduction of equity incentives, a further conclusion can therefore be obtained for a given effort level $(\hat{e}_1,\hat{e}_2)$:

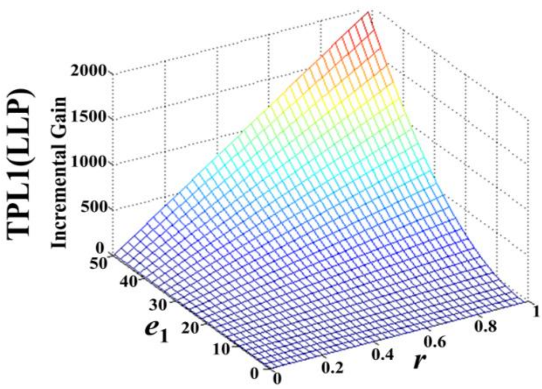
(1) A fixed remuneration $U^{-1}(c(\hat{e}^2)+\underline{U}^2)$ is received by TPL2. A remuneration $U^{-1}(c(\hat{e}^1)+\underline{U}^1+M')$ is obtained by postal logistics in the role of the LLP.

(2) TPL2 is assumed to continue obtaining a reservation utility denoted as $\underline{U}^2$. The LLP is assumed to derive a reservation utility denoted as $\underline{U}^1$ from logistics services. The total utility of the LLP is denoted as $\underline{U}^1+r(x_k-z)$. The additional monitoring cost originally paid is converted into equity incentives granted to the LLP.

(3) The calculation results indicate that equal sharing of remuneration payments between S and EC is no longer maintained after the implementation of the equity structure. Remuneration payments are instead determined by the equity ratio. The transfer payment made by S is denoted as $\frac{1}{2-r}U^{-1}(c(\hat{e}^1)+\underline{U}^1+M')+\frac{1}{2}U^{-1}(c(\hat{e}^2)+\underline{U}^2)$. The actual payment made by EC is denoted as $\frac{r-1}{r-2}U^{-1}(c(\hat{e}^1)+\underline{U}^1+M')+\frac{1}{2}U^{-1}(c(\hat{e}^2)+\underline{U}^2)$.

3.2 Case Analysis

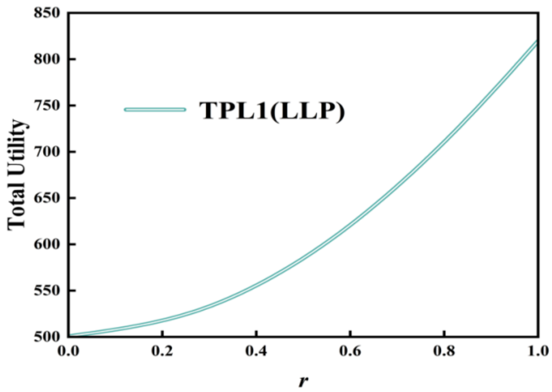
The logistics partners of a platform-based agricultural circulation service provider (EC) include China Post Logistics (TPL1) and SF Express (TPL2). An order for Turpan grapes destined for Beijing is received by the EC. Direct shipment from a warehouse near the production base is required. The reservation utilities of the two logistics firms are specified as $\underline{U}^1=500$ and $\underline{U}^2=300$, respectively. Logistics services are provided only when realized payoffs are not lower than the corresponding reservation levels. Provision of high-quality logistics services requires effort, and costs are incurred in proportion to effort levels. Without loss of generality, the cost function is specified as $c(e_i) = 50e_i$, where i = 1, 2. Each additional unit of effort therefore generates an additional cost of 50 units. At a given effort level, the utility of each logistics provider is determined by the remuneration *w* received. For simplicity, the utility function is assumed to be $U(w) = w$.



Source: created by the authors.

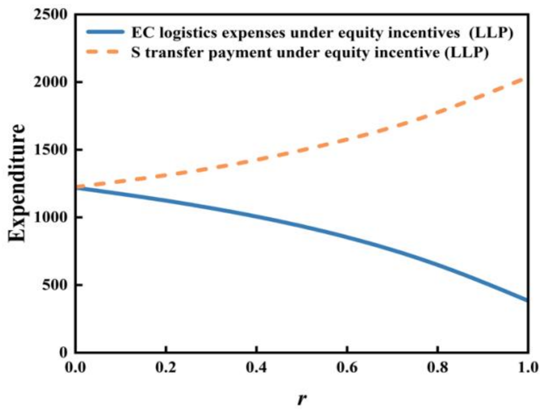
Figure 2. **Variation Trends of the Additional Income of TPL1 with Respect to Effort Level and Equity Ratio**

To ensure timely and intact delivery of grapes, monitoring of China Post Logistics is required by the EC. A monitoring cost of $M^1 = 300$ is therefore incurred. At the same time, the EC knows that a lower monitoring cost is faced by China Post Logistics when supervising SF Express. The exact magnitude of the cost difference is not observable. Accordingly, a monitoring compensation of $M^2 = 200$ is paid by EC. The compensation level is set below the monitoring cost borne by EC. After receiving compensation, China Post Logistics sets the expected monitoring cost for supervising SF Express at $M^L = 100$. After equity shares are obtained, China Post Logistics exerts greater supervisory effort. The actual monitoring cost is thus increased to $M' = 150$. At each possible effort level, the EC cannot directly observe the logistics providers' actions. However, additional revenue generated for EC can be observed, which is denoted as x_k. A positive relationship between additional revenue and effort level is assumed. The relationship is specified as $x_k(e_i) = 2e_i^2$. Logistics providers are then rewarded by EC with a fixed proportion of the additional revenue, and a reward rate of 60% is applied. The reward function is specified as $z(x_k) = 0.6x_k$. Final calculations indicate that cost–benefit outcomes of TPL2 remain unchanged before and after the introduction of equity incentives. By contrast, additional income earned by China Post Logistics increases with equity ratio. Within a certain range, higher effort levels exerted in logistics services are associated with greater additional returns (*Figure 2*).



Source: created by the authors.

Figure 3. **Variation of TPL1's Total Utility with Respect to the Equity Structure *r***



Source: created by the authors.

Figure 4. **Changes in Supplier S's Transfer Payment and EC's Logistics Expenditure with Respect to *r***

Under the effort profile (e_1, e_2) = (20, 10), the total utility obtained by China Post Logistics is evaluated for different equity ratios r. As the equity-holding party, China Post Logistics obtains a higher level of total utility as the equity share increases. When $r = 0$, equity incentives are absent. Under such conditions, total utility is equal to the reservation utility of 500, as illustrated in *Figure 3*. *Figure 4* depicts the changes in EC's logistics expenditures and transfer payments made by the agricultural product supplier S under different equity structures. Under the LLP model, logistics payments are equally shared by the two parties when equity incentives are not introduced. After the introduction of equity incentives, transfer payments made by supplier S increase with the equity ratio. By contrast, direct logistics expenditures incurred by the EC exhibit a decreasing trend. The condition $r \neq 1$ is required. Otherwise, the resulting expression would be rendered meaningless.

4. Discussion

A cost–benefit analysis is conducted, and equity incentive scenarios are simulated for the LLP model. Within an alliance-based hybrid agricultural logistics framework, postal logistics is positioned as the leading entity. Several theoretical and practical insights are acquired. A fresh perspective is provided for optimizing coordination in China's digitally enabled agricultural logistics systems.

First, with respect to model construction and cost–benefit analysis, a multi-principal–multi-agent framework is adopted. Agricultural suppliers (S), platform-based circulation service providers (EC), and two third-party logistics providers (TPL1 and TPL2) are incorporated into a unified analytical system. Limitations of existing studies are addressed. Prior literature has often been confined to single-actor perspectives or static analyses. For example, Zhou *et al.* (2011) focused primarily on cost comparisons between the LLP model and direct outsourcing. Dynamic incentive mechanisms among multiple actors were not considered. In addition, potential moral hazard issues inherent in the LLP arrangement are revealed. In the absence of additional incentives, postal logistics may reduce supervision intensity , and exert lower effort levels. Overall supply chain performance is therefore likely to be impaired. Consistent with the findings of Hobbs (1996), who emphasized the tendency toward opportunistic behavior under high asset specificity, the manifestation of such risks in multi-actor collaborations is further quantified.

Second, after the introduction of an equity incentive mechanism, the LLP's incremental returns increase significantly as equity shares rise. Supervisory effort and logistics effort are simultaneously strengthened, resulting in the improved operational efficiency of the overall supply chain. The applicability of principal–agent theory to agricultural logistics practice is thus corroborated. Consistency is also observed with prior research on equity incentives and performance contracts by Kapacinskaite and Mostajabi (2024) and Zhang *et al.* (2024). Scenario analysis further indicates that, within a reasonable range of equity allocations, fixed compensation received by TPL2 remains stable. Transfer payments made by supplier S increase, whereas direct logistics expenditures borne by EC decrease. A balanced outcome among all parties is therefore achieved. These results complement empirical evidence provided by Liang *et al.* (2026) on the effects of multi-actor coordination on consumer satisfaction. The analysis further demonstrates that equity incentives can achieve cost control and service quality improvement. Cooperative relationships between upstream and downstream participants are simultaneously preserved.

Finally, sensitivity analyses with respect to effort levels, monitoring costs, and equity ratios are conducted. Dynamic interactions between logistics model innovation and incentive mechanisms are thereby revealed. The analysis indicates that equity incentives strengthen the LLP's supervision of TPL2. Delivery timeliness for fresh products is indirectly improved, and delivery safety is enhanced. Service quality in digitally enabled fresh-food logistics is consequently raised. Compared with earlier studies focusing on single logistics actors, fixed compensation schemes, or short-term cooperation effects, such as Akkerman *et al.* (2010), the present study adopts a broader system perspective. Evolutionary patterns of supply chain coordination under multiple actors and diverse incentive types are revealed. Quantitative guidance is provided for policymakers and practitioners in the design of cooperative logistics arrangements. Emphasis is placed on the integrated roles of equity incentives and monitoring effectiveness. Balanced interests between upstream and downstream participants are also highlighted in supporting sustainable and efficient logistics service models.

Conclusions and Implications

Main Findings

To explore efficient organizational arrangements for agricultural logistics in a digital-intelligence context, this study examines digitally enabled agricultural logistics and addresses practical challenges. Such challenges include long logistics chains, high post-harvest losses, elevated transaction costs, and information asymmetry. An alliance-based hybrid logistics model is formulated. Within a LLP framework led by postal logistics, a multi-principal–multi-agent theoretical approach is introduced together with an equity incentive mechanism. Participants' effort choices are systematically examined. Cost and payoff allocations are also analyzed, and incentive effects are further evaluated. In addition, scenario simulations are employed to trace the coevolution of multiple actors in China's agricultural supply chains. The principal findings are presented as follows:

(1) In the absence of equity incentives, supervisory responsibilities are primarily borne by postal logistics acting as the LLP. Only reservation utility is attained, so willingness to engage in monitoring is limited. Relatively low effort is exerted by the third-party logistics provider TPL2. Operational efficiency of the overall supply chain is consequently constrained. Although advantages over direct outsourcing are provided by the LLP arrangement in terms of cost control and governance structure, exposure to moral hazard remains. Effective incentive constraints are insufficient under such conditions.

(2) After the introduction of equity incentives, incremental returns of the LLP increase significantly with equity share. Supervisory intensity is strengthened, and logistics effort is enhanced. Service quality and operational efficiency across the supply chain are therefore improved. At the same time, direct logistics expenditures incurred by the platform-based circulation provider are reduced as equity allocations rise. Transfer payments made by supplier S increase with equity shares. However, aggregate payoff levels of supplier S rise substantially, and successful sales volumes expand. Overall, the results demonstrate that equity incentives are effective in improving supply chain efficiency. Interests of multiple stakeholders are simultaneously safeguarded.

(3) The analysis further shows that equity incentives strengthened the LLP's contract compliance. Supervision intensity and coordination effectiveness are enhanced. Delivery timeliness and safety of fresh products are indirectly improved, and end-customer service levels are consequently raised. Improved consumer satisfaction contributes to the reinforcement of brand equity for digitally enabled logistics platforms. User retention is also strengthened, thus fostering virtuous cycles among supply chain participants. Multi-party gains are ultimately achieved.

(4) Within a reasonable range of equity allocation, stable cooperative relationships can be formed among participants. A viable institutional foundation for sustainable operation is therefore established under the alliance-based hybrid logistics model. Problems such as unsold produce and supply chain disruptions can

be mitigated. A practicable pathway is also provided for optimizing China's digital-intelligence agricultural logistics system.

Compared with existing research on agricultural logistics, the present study places greater emphasis on incentive mechanisms rather than on the structural design of logistics organizations alone. By embedding a multi-principal–multi-agent framework into digitally enabled agricultural circulation contexts, strategic interactions among multiple actors are more accurately characterized. Incentive constraints arising from multi-actor collaboration are also more effectively captured. The findings provide policymakers with theoretical justification for the design of collaborative governance arrangements. Quantitative evidence is also offered to support differentiated incentive schemes. Practical implications are further derived for promoting high-quality development of intelligent agricultural logistics in China.

Management Implications

This study makes three primary contributions:

(1) First, with respect to analytical perspective and theoretical extension, conventional analyses emphasizing cost efficiency or mode comparison are departed from. Incentive design is positioned as the central analytical thread. The internal mechanism linking incentive arrangements, effort provision, and performance outcomes in digitally enabled hybrid agricultural logistics systems is systematically uncovered. From a methodological perspective, a multi-principal–multi-agent framework is innovatively applied to a digitally enabled logistics context. A multi-actor game is constructed, wherein platform operators, a postal leadership logistics partner, third-party logistics firms, and agricultural suppliers are incorporated. A more faithful representation of the strategic environment underlying complex collaborative relationships is thereby achieved. The applicability of supply chain incentive theory is further extended.

(2) Second, with respect to mechanism design and research methods, an equity incentive scheme is incorporated into the alliance-based hybrid logistics model. A systematic analytical framework is developed to examine how variations in equity share influence payoff allocation, effort provision, and monitoring intensity. Scenario simulations are further employed. Dynamic evolution among multiple actors under different incentive strengths is illustrated. Gaps in the existing literature concerning the dynamic effects of incentive mechanisms are addressed. Robustness of the results is enhanced, and practical interpretability is improved.

(3) Third, with respect to policy relevance and managerial implications, close alignment is maintained with China's ongoing digital transformation of agricultural logistics. A postal LLP-led alliance is proposed as an operational pathway. Fragmented organization, weak oversight, and insufficient incentives are thereby addressed. Quantified findings provide actionable guidance for governments. Improvement of collaborative governance can be supported. Practical reference is also offered for firms seeking to design differentiated incentive schemes. Overall, the study supports the advancement of China's digital-intelligence agricultural logistics toward higher quality and greater resilience.

Research Limitations and Perspectives

Several limitations of this study are acknowledged. First, the model is calibrated to a single supply chain configuration and a specific regional setting. Generalizability of the conclusions may be constrained. Second, heterogeneity among suppliers, LLPs, and third-party logistics firms is not fully captured by the model. Seasonal demand fluctuations are not explicitly incorporated. Competitive market dynamics that may affect system performance are also omitted. Third, the simulation analysis primarily focuses on single-factor variations. Nonlinear interactions among equity share, monitoring cost, and effort levels are not fully characterized.

Future research can be advanced along three directions. First, the analytical framework can be extended to multi-regional and multi-product supply chains. Cross-sectional comparisons can be enabled, and external validity can be broadened. Second, firm-level behavioral heterogeneity can be incorporated. Market competition and dynamic demand fluctuations can also be introduced. Real-world supply chain complexity can be more accurately reflected. Third, big data, artificial intelligence, and machine learning tools can be leveraged. Nonlinear mechanisms between incentive design and monitoring behavior can be further explored. More forward-looking and data-driven decision support can be provided for optimizing digital-intelligence agricultural logistics models.

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NUOSAVYBĖS SKATINIMO MECHANIZMAS ALJANSU GRINDŽIAMAME ŽEMĖS ŪKIO PRODUKTŲ LOGISTIKOS MODELYJE SKAITMENINIO INTELEKTO PLATFORMOSE

Linzhi Wang, Jing Xu

Santrauka. Kinijoje žemės ūkio logistikos sistema vis dar susiduria su nuolatiniais iššūkiais: pernelyg ilga tiekimo grandine, dideliais nuostoliais po derliaus nuėmimo ir aukštomis sandorių sąnaudomis. Dėl to dažnai atsiranda rinkos neatitikimų – dalis produkcijos lieka neparduota, o pirkimo procesai tampa sudėtingi. Šios problemos sulaukia vis didesnio politikos formuotojų, pramonės atstovų ir akademinių tyrėjų dėmesio. Esami tyrimai daugiausia skirti investicijoms į infrastruktūrą, informacinių sistemų kūrimui ir individualių logistikos modelių optimizavimui. Tačiau trūksta sistemingų tyrimų apie daugiaagentį bendradarbiavimo valdymą ir stabilius skatinimo mechanizmus skaitmeninio intelekto platformose. Siekiant užpildyti šią spragą, buvo sukurtas konceptualus aljansu pagrįsto hibridinio žemės ūkio logistikos modelis, Kinijos logistikos praktika sujungta su tarptautine patirtimi. Remiantis daugiaagenčiu teoriniu pagrindu, buvo išnagrinėta tiekimo grandinė, kurią sudaro žemės ūkio tiekėjai, skaitmeninių platformų įmonės ir trečiųjų šalių logistikos paslaugų teikėjai. Buvo pristatytas nuosavybės skatinimo mechanizmas, skirtas dalyvių pastangų lygiui, išmokų struktūroms ir bendradarbiavimo stabilumui analizuoti. Modeliavimo rezultatai rodo, kad papildoma pagrindinio agento grąža reikšmingai didėja augant nuosavybės daliai ir plečiant paslaugų teikimą. Pagrindinio kliento logistikos išlaidos mažėja didėjant nuosavybės paskirstymui, o pavaldžių kliento ir agentų atlyginimai iš esmės išlieka stabilūs. Taigi visi tiekimo grandinės dalyviai patiria gerinantį Pareto rezultatą. Išvadose pateikiamas naujas teorinis pasikartojančios neparduotų žemės ūkio produktų problemos paaiškinimas, taip pat vertingos vadybos įžvalgos apie logistikos struktūrų ir skatinimo mechanizmų kūrimą skaitmeninio intelekto platformų aplinkoje.

Reikšminiai žodžiai: žemės ūkio logistika; logistikos modeliai; skaitmeninio intelekto platformos; skatinimo mechanizmai.