ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

Study on the Benefit Distribution Mechanism in a Mixed Dual-Channel Agricultural Supply Chain under Variable Supply Conditions

Zifu Fan, Zhiqiao Sun*

Chongqing University of Posts and Telecommunications, Chongqing, China

*Corresponding Author

Abstract

This study delves into the dynamics of mixed dual-channel supply chains for agricultural products, set against the backdrop of the strategic shift labeled "Big Warehouse Moving East." We tailor our cooperation decision model for these supply chains to three distinct scenarios: shortage of agricultural products, standard supply, and surplus supply. Our approach constructs a benefit distribution model that accounts for the weight ratios of individual supply chain members. We employ a simulation study featuring two agricultural enterprises, Kashgar Xinxin Fruit Industry and Tai Jizhi Sales, as our case subjects. The findings corroborate the efficacy of our proposed mixed dual-channel benefit distribution model in fluctuating supply conditions. They reveal a direct positive correlation between the market share of each supply chain participant and their corresponding distribution share under centralized decision-making processes. This research not only validates the scientific underpinnings of our model but also establishes a robust theoretical base for future investigations in this domain.

Keywords

Variable Supply; Hybrid Dual Channel; Agricultural Supply Chain; Benefit Distribution.

1. Introduction

Since its inception in 2017 under the aegis of the Shandong Provincial Aid Department, the LuKa Special Agricultural Products Supply and Marketing Union has spearheaded the "Great Warehouse Eastward" initiative. This project aims to bolster Kashgar's special agricultural and sideline products by reducing transportation expenses and enhancing the supply-demand market nexus. Notably, Kashgar Xinxin Fruit and Tai Agricultural Products Sales have deepened their collaboration through this initiative, fostering a supportive market environment for consumers. In the realm of supply chain coordination research, domestic and international scholars have made significant contributions. Zheng (2019)[1] delved into profit dynamics within the agricultural supply chain, examining the impact of enhanced revenue-sharing contracts. Taylor (2006)[2] offered insights on refining demand management processes via supply chain cooperation. Chung (2016)[3] developed a model for shared freshness cost contracts among supply chain entities, aimed at optimizing each participant's profits. Exploring the interplay between freshness efforts, consumer channel preferences, and decision-making, Bai (2019) [4]observed that the introduction of online retail channels can lead to conflicts between different sales channels. Tang (2017)[5] employed differential analysis to evaluate optimal strategies under both centralized and decentralized (Nash and Stackelberg) decision-making frameworks. Zhang (2021)[6] analyzed the effects of retailers' fairness concerns, finding that revenue-sharing contracts could facilitate supply chain coordination. Peng (2017) [7]also utilized differential strategies to study optimal decisions in various decision-making contexts. Blackburn (2019) [8]investigated supply chain strategies for perishable goods by

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

focusing on their marginal time value. Additionally, Fan (2019) [9]created a coordination model under an agricultural revenue-sharing contract to elucidate the mechanisms driving coordination decisions and offline wholesale pricing. However, there is a noticeable gap in the existing literature concerning consumer satisfaction with delivery services, particularly in the context of burgeoning online channels. This study aims to address this gap by exploring the benefit distribution mechanism within a mixed dual-channel agricultural supply chain under variable supply scenarios.

2. Demand Analysis of Agricultural Supply Chain Members under Variable Supply Scenarios

2.1. Problem Description and Model Assumptions

This section utilizes the Stackelberg game model to construct and analyze a comparative model focusing on individual versus cooperative decision-making in agricultural supply chains. The model explores two primary sales channels. In the first, agricultural agents (denoted as X) wholesale products to retailers (T) at a wholesale price (ω). Retailers then sell these products in traditional stores at a price (P_1). Conversely, X agents also have the option to sell directly to end consumers at a price (P_2) via an online direct sales platform. Simultaneously, T retailers may choose to engage in direct online sales to end consumers at the same price (P_1). The model is predicated on several key assumptions:

1) The initial production time of the product is considered time 0, with subsequent times denoted by t.

2) The maximum shelf life of the produce is represented by T. Produce that spoils within this period is deemed unsellable, holding no market value and incurring no disposal costs.

3) Other costs, including inventory and e-commerce-related expenses, are assumed to be constant. The freshness cost function is represented by $c_x = k\xi^2$ while customer satisfaction related to logistics and distribution is denoted by $c_l = b\psi Q$.

4) The potential size of the overall agricultural market is quantified as a .

5) In the cooperative model, it is assumed that there is complete trust among members and that decisions are made with a collective perspective.

6) It is assumed that supply chain members are restricted from selling goods at more than one-time their cost.

2.2. Parameters and Variables

c : represents the unit production cost for agricultural producers.

ψ : denotes agricultural distribution satisfaction.

S : signifies the total supply of agricultural products $Q_1 + Q_2 + Q_3 \leq S$.

α : indicates the consumer's price sensitivity for agricultural products.

λ : indicates the sensitivity coefficient of consumers to the freshness of the produce.

ϑ : indicates the sensitivity coefficient of consumers to the delivery speed of agricultural products.

ξ : denotes the real-time freshness of the produce as a function.

Of which, $\xi = \xi_0 - \int_0^T b(\frac{t}{T})^2 dt + k\xi_1^2$.

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

Where, ξ_0 represents the initial freshness, ξ_1 denotes artificially enhanced freshness retention, and b denotes the natural decay rate of freshness.

P_0: indicates the price of agricultural products as expected by consumers.

Q_1: indicates the offline demand from retailers.

Q_2: indicates the amount of online demand from retailers.

Q_3: indicates the amount of offline demand from agents.

Where, the demand expression is represented as $Q=(1-\rho)a-\alpha_2\Delta P-\beta_2\left[\int_0^T b(\frac{t}{T})^2 dt-\xi_1\right]+\vartheta\psi$.

2.3. Analysis of Agricultural Supply Chain Members' Demand based on Different Supply Scenarios

2.3.1. Demand Analysis under Supply Shortage

In scenarios where retailers cannot achieve revenue-optimal supply through independent decisions, a state of supply shortage is identified.

(1) Individual Decision-Making

In this condition, agricultural agents and retailers capitalize on the scarcity of agricultural products to generate excess profits. However, retailers are unable to attain optimal returns. The following factors influence the agents' demand:

$$Q_3=\rho a-\alpha_3(P_2-P_0)\le S$$

As supply increases, agents adjust their strategy by lowering prices and increasing shipments to retailers, as described by equations (1) and (2):

$$Q_3\le S \tag{1}$$

$$Q_3=\rho a-\alpha_3(P_2-P_0)-\lambda_3\left[\int_0^T b(\frac{t}{T})^2 dt-\xi_2\right]+\vartheta_2\psi_2 \tag{2}$$

Equations (3) and (4) limit retailers' options following the receipt of produce:

$$Q_1+Q_2=S-Q_3 \tag{3}$$

$$Q_1+Q_2=(1-\rho)a-(\alpha_1+\alpha_2)(P_1-P_0)-(\lambda_1+\lambda_2)\left[\int_0^T b(\frac{t}{T})^2 dt-\xi_1\right]+\vartheta_1\psi_1 \tag{4}$$

In this independent decision-making scenario, reliance on agents results in high business risk. Consequently, seeking cooperation becomes a secondary strategy for retailers.

(2) Collaborative Decision-Making

In this model, as shown in equations (5) and (6), internal decisions and the available supply both affect the corresponding demand quantity:

$$Q_1+Q_2+Q_3=a-(\alpha_1+\alpha_2)(P_1-P_0)-\alpha_3(P_2-P_0)-(\lambda_1+\lambda_2+\lambda_3)\left[\int_0^T b(\frac{t}{T})^2 dt-\xi_2\right]+(\vartheta_1+\vartheta_2)\psi_1 \tag{5}$$

$$Q_1+Q_2+Q_3=S \tag{6}$$

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

2.3.2. Analysis of Demand in Oversupply Conditions

In this phase, retailers achieve maximum revenue, whereas agents lose their absolute dominance in the supply chain, as noted by Jiang (2019)[10].

(1) Individual decision making

Under separate decision making, the retailer keeps the optimal and normal case decision consistent with the supply of:

$$Q_1+Q_2=(1-\rho)a-(\alpha_1+\alpha_2)(P_1-P_0)-(\lambda_1+\lambda_2)\left[\int_0^T b(\frac{t}{T})^2\,dt-\xi_1\right]+\vartheta_1\psi_1$$

In this stage, the agent has to ensure that the price of the agricultural product sold is higher than its residual value, with the following restrictions (7) (8).

$$Q_3 \le S-Q_1-Q_2 \tag{7}$$

$$Q_3=\rho a-\alpha_3(P_2-P_0)-\lambda_3\left[\int_0^T b(\frac{t}{T})^2\,dt-\xi_2\right]+\vartheta_2\psi_2 \tag{8}$$

The corresponding returns are:

$$\Pi_2=(\omega-c)(Q_1^*+Q_2^*)+(P_2-c-b_2\psi_2)Q_3-k_2\xi_2^2-s(S-Q_1^*-Q_2^*-Q_3)$$

(2) Collaborative decision-making

Retailers and agents choose to cooperate in the state of excess supply, when the demand and supply chain relationship is as (9) (10).

$$Q_1+Q_2+Q_3=a-(\alpha_1+\alpha_2)(P_1-P_0)-(\lambda_1+\lambda_2+\lambda_3)\left[\int_0^T b(\frac{t}{T})^2\,dt-\xi_2\right]+(\vartheta_1+\vartheta_2)\psi_1-\alpha_3(P_2-P_0) \tag{9}$$

$$Q_1+Q_2+Q_3 \le S \tag{10}$$

The corresponding overall supply chain revenue is:

$$\Pi=(P_1-c)Q_1+(P_1-c-b_1\psi_1)Q_2+(P_2-c-b_1\psi_1)Q_3-k_2\xi_2^2-s(S-Q_1-Q_2-Q_3)$$

3. Design and Application of Supply Chain Benefit Distribution Mechanism

3.1. Model Assumptions

The assumptions in this paper are as follows.

1) assumes that the process of benefit distribution is played by n subjects.

2) assumes that each subject seeks to maximize his or her personal interests.

3) guarantee that the sum of the profits distributed by each entity is equal to the maximum total revenue of the supply chain.

4) assuming that the proportion of benefit distribution is influenced by the weight share of each participating subject.

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

3.2. Variable Description

g_i denotes the status weight of the members of the cooperative model i in the supply chain, where i denotes supply chain participants, 1 denotes agricultural agents and 2 denotes retailers.

Z_i^* denotes the benefits shared by the members of i under the cooperative model.

Z^* denotes the sum of the benefits shared by so members in the cooperative model.

E Indicates the use of a collection of reasonable distribution programs. $E(e_1, e_2 \ldots e_n)$.

e^* denotes the optimal allocation scheme. $e^*(k_1^*, k_2^*)$.

k_i denotes the actual revenue distribution coefficient of the members of the cooperative model i in the cooperative model.

3.3. Model Building

The objective function is:

$$MAX \sum_{i=1}^{n} (Z_i^* - \Pi_i^*)^{g_i}$$

The constraint is:

$$\begin{cases} \sum_{i=1}^{n} Z_i^* = Z^* \\ \sum_{i=1}^{n} g_i = 1 \\ \sum_{i=1}^{n} k_i^* = 1 \end{cases}$$

The expression for the optimal decision revenue of the retailer in the independent operation model is:

$$\Pi_1^* = (P_l - \omega)Q_l + (P_l - \omega - b_1\psi_1)Q_2 - k_1\xi_1^2$$

Among them:

$$P_1^* = \frac{(1-\rho)a - (\lambda_1 + \lambda_2)\left[\int_0^T b(\frac{t}{T})^2 dt - \xi_1\right] + (\vartheta_1 + b_1\alpha_2)\psi_1}{2(\alpha_1 + \alpha_2)} + \frac{P_0 + \omega}{2}$$

$$Q_1 + Q_2 \le S - Q_3$$

The expression for the optimal decision gain in the agent's individual decision is:

$$\Pi_2^* = (\omega - c)(Q_l^* + Q_2^*) + (P_2 - c - b_2\psi_2)Q_3 - k_2\xi_2^2 - s(S - Q_l^* - Q_2^* - Q_3)$$

Among them:

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

$$P_2^* = \frac{a - \lambda_3 \left[\int_0^T b(\frac{t}{T})^2 dt - \xi_2 \right] + \vartheta_2 \psi_2}{2\alpha_3} - \frac{s + b_2 \psi_2 - P_0 - c}{2}$$

$$\omega^* = \frac{(1-\rho)a - (\lambda_1 + \lambda_2) \left[\int_0^T b(\frac{t}{T})^2 dt - \xi_1 \right] + \vartheta_1 \psi_1}{0.5(\alpha_1 + \alpha_2)} - 2P_1 + 2P_0 + c$$

$$Q_1 + Q_2 + Q_3 \le S$$

The total revenue under cooperative decision making operation is:

$$Z^* = (P_1^* - c)Q_1 + (P_1^* - c - b_1\psi_1^*)Q_2 + (P_1^* - c - b_1\psi_1^*)Q_3 - k_2\xi_2^{*2} - s(S - Q_1 - Q_2 - Q_3)$$

Among them:

$$Q_1 + Q_2 + Q_3 \le S$$

Under the cooperative decision, the retailer distributes profits as:

$$Z_1 = k_1 Z^*$$

Under the cooperative decision, the profit of agricultural agents is:

$$Z_2 = k_1 Z^*$$

In summary, the mixed dual-channel supply chain revenue allocation model for agricultural products, with the objective function:

$$MIN - ((Z_2^* - \Pi_2^*)^{g_2} (Z_1^* - \Pi_1^*)^{g_1})$$

The constraint is:

$$\begin{cases} Z_1^* = k_1 Z^* \\ Z_2^* = k_2 Z^* \\ g_1 + g_2 = 1 \\ k_1 + k_2 = 1 \\ Z_2^* - \Pi_2^* \ge 0 \\ Z_2^* \ge 0 \\ Z_1^* - \Pi_1^* \ge 0 \\ Z_1^* \ge 0 \end{cases}$$

3.4. Determination of Status Weights

In order to increase the reliability of evaluation, this paper first introduces the projection method to evaluate each member's corporate soft power, contribution factors, risk factors and other indicators separately, and then normalizes them.

3.4.1. Evaluation Data Collection

Four experts in the field were invited to D_1、D_2、D_3、D_4 to form a decision-making committee.

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

3.4.2. Calculate the Average Decision Matrix

$$\begin{cases} u_{11}^{l} = 1 - \prod_{k=1}^{3}(1 - u_{k11}^{l})^{\frac{1}{3}}, \\ u_{11}^{u} = 1 - \prod_{k=1}^{3}(1 - u_{k11}^{u})^{\frac{1}{3}} \\ v_{11}^{l} = \prod_{k=1}^{3}(v_{k11}^{l})^{\frac{1}{3}}, \\ v_{11}^{u} = \prod_{k=1}^{3}(v_{k11}^{u})^{\frac{1}{3}} \end{cases}$$

Table 1 can be obtained from the calculation of the solution.

Table 1. Table of average decision matrix

	Corporate Soft Power	Contributing factors	Risk Factors
Kashin Xinxin	([0.48,0.63]), [0.17,0.29])	([0.35,0.41]), [0.34,0.49])	([0.36,0.51]), [0.30,0.42])
Thai Agricultural Products	([0.30,0.45]), [0.35,0.47])	([0.13,0.30]), [0.26,0.45])	([0.63,0.78]), [0.10,0.22])

3.4.3. Splitting the Matrix

Both the evaluator decision matrix and the average decision matrix derived from step 2 are split.

3.4.4. Find the Bidirectional Projection of the Average Matrix and the Evaluator's Decision Matrix

$$TY\left(\overline{X}^{0}, X_{k}^{0}\right) = \frac{1}{1 + \left| \frac{\overline{X}^{0} X_{k}^{0}}{\left\| \overline{X}^{0} \right\|} - \frac{\overline{X}^{0} X_{k}^{0}}{\left\| X_{k}^{0} \right\|} \right|}$$

Among them:

$$\left\| \overline{X}^{0} \right\| = \sqrt{\sum_{i=1}^{2}\sum_{j=1}^{3}(w_j \overline{X}^{0ij})^2} = \sqrt{\sum_{i=1}^{2}\sum_{j=1}^{3} w_j^2[(u_{ij}^{l})^2 + (u_{ij}^{u})^2]}$$

$$\overline{X}^{0} X_{k}^{0} = \sum_{i=1}^{2}\sum_{j=1}^{3} w_j^2 (u_{ij}^{l} u_{kij}^{l} + u_{ij}^{u} u_{kij}^{u})$$

The bidirectional projection values are obtained according to Eq. Table 2 below.

Table 2. Table of bidirectional projection values of the decision matrix

	Affiliation	Unaffiliatedness
$TY\left(\overline{X}^{0}, X_{1}^{0}\right)$	0.9926	0.9820
$TY\left(\overline{X}^{0}, X_{2}^{0}\right)$	0.9947	0.9583
$TY\left(\overline{X}^{0}, X_{3}^{0}\right)$	0.9930	0.9837
$TY\left(\overline{X}^{0}, X_{4}^{0}\right)$	0.9938	0.9885

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

3.4.5. Calculate the Similarity between the Evaluator and the Group

Take $\theta = 0.6$ and find the similarity $D_1 = 0.9884, D_2 = 0.9801, D_3 = 0.9893$, $D_4 = 0.9917$. Calculate the weights of the experts:

$$\begin{cases} wd_1 = \dfrac{D_1}{\sum_{k=1}^{4} D_k} = 0.2502 \\ wd_2 = \dfrac{D_2}{\sum_{k=1}^{4} D_k} = 0.2482 \\ wd_3 = \dfrac{D_3}{\sum_{k=1}^{4} D_k} = 0.2505 \\ wd_4 = \dfrac{D_4}{\sum_{k=1}^{4} D_k} = 0.2511 \end{cases}$$

Assembly Matrix:

$$J(u,v)=\sum_{j=1}^{n} w_j a_j = ([1-\prod_{j=1}^{n}(1-a_j)^{w_j}, [1-\prod_{j=1}^{n}(1-b_j)^{w_j}]][\prod_{j=1}^{n} c_j^{w_j}, \prod_{j=1}^{n} d_j^{w_j}])$$

3.4.6. Determine the Ratio

Combining the above with the knowledge that θ = 0.6, the final ratio of each member was found by weighting the affiliation and non-affiliation as in Table 3.

Table 3. Kashgar Xinxin and Tai supply agricultural products weight solving ratio table

	Final Score	Actual score
Kashin Xinxin	0.7667	0.52
Thai Agricultural Products	0.7094	0.48

4. Example Analysis

4.1. Parameter Determination

4.1.1. Cost Price

The production process incurs an approximate cost of 2 yuan per kilogram. For practical exercises, this is represented as $c = 9Q$.

4.1.2. Supply Chain Member Subject Weights

Based on the analysis in the previous section, the final weight ratio for supply chain members is determined to be (0.52, 0.48).

4.1.3. Other Parameters

The initial market size is established at $a = 1.8$ million kg, and the sales cycle for dates is set at $T = 12$ months. The price sensitivity coefficients for consumers, in the context of agents online, retailers online, and retailers offline, are sequentially 0.1, 0.2, and 0.3. The freshness sensitivity coefficients follow the order of 0.3, 0.1, and 0.2. Additionally, the delivery satisfaction sensitivity coefficient, representing a higher requirement, is set at 0.08.

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

4.2. Solving Analysis

4.2.1. Comparison of Results under Each Decision

First, the algorithm's parameters are input into the model. The outcomes of this process are illustrated in Figure 1.

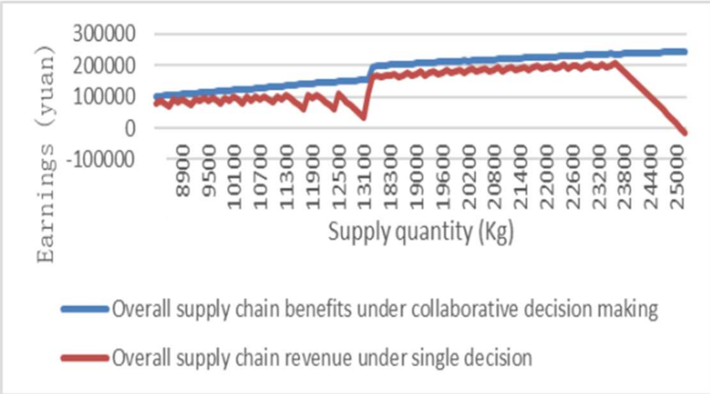

Figure 1. Comparison of benefits under single decision and centralized decision

4.2.2. The Effect of Supply on the Optimal Allocation Ratio

The particle swarm optimization algorithm is utilized to determine the optimal allocation ratio, as illustrated in Figure 2.

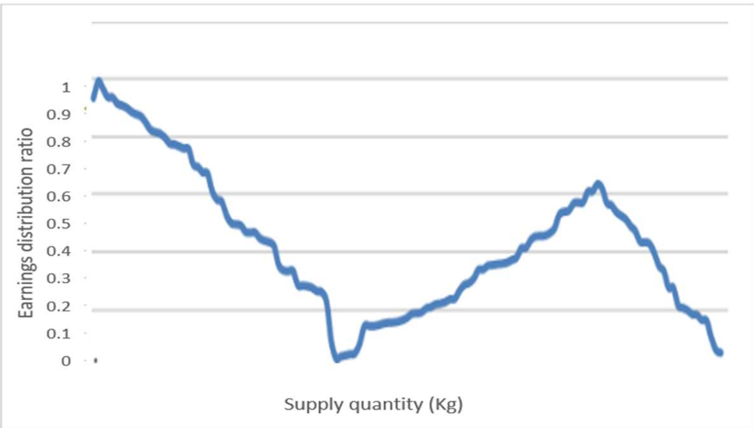

Figure 2. Trend of revenue allocation ratio with supply chain

The analysis indicates that the revenue distribution ratio escalates with an increase in supply, peaking at around 0.6.

4.3. Sensitivity Analysis

The analysis involves altering the status weights of supply chain members to examine their impact on the revenue distribution proportion. The respective values are detailed in Table 4 below.

Table 4. Supply Member Weighting Values

	Agent Status Weighting	Retailer Status Weights
Hypothesis I	0.2	0.8
Hypothesis II	0.5	0.5
Hypothesis III	0.8	0.2

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

The outcomes of this analysis are presented in Figure 3.

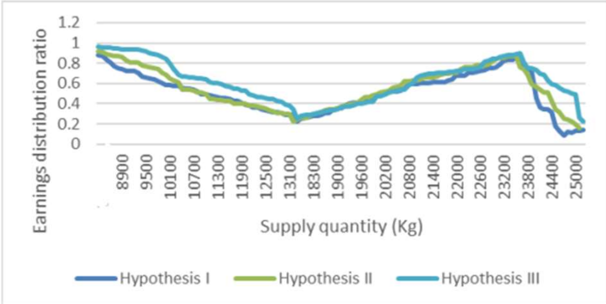

Figure 3. Benefit Distribution Proportion Under Different Weights

The findings from this study suggest that the revenue allocation ratio is consistently influenced by the change in weight, showing a positive correlation.

5. Conclusion

In conclusion, this paper successfully develops a benefit allocation model that accounts for the weight share of each supply chain member. Two agricultural product enterprises, Kashi Xinxin Fruit Industry and Tai Supply and Sales, were selected for arithmetic simulation. The results validate the efficacy of the mixed dual-channel benefit distribution model in variable supply situations. It is observed that the market share of each supply chain member positively correlates with their distribution share in centralized decision scenarios. However, it is important to note that this study does not consider the fixed operational costs of supply chain members. Including fixed operational costs in future studies could reveal a comparative advantage for centralized decision-making.

Acknowledgments

Natural Science Foundation.

References

[1] Zheng Q, Zhang Lei. Revenue sharing contract of fresh agricultural products under the "farm-to-super docking" model[J]. Journal of System Management,2019,28(04):742-751.

[2] Taylor D H. A framework for demand management and improvement in agri-food supply chains [J]. The International Journal of Logistics Management,2006,17(2):163-186.

[3] Chung Y, Dye, Chih T, et al. A note on "Coordinating a supply chain for deteriorating items with a revenue sharing and cooperative investment contract" [J]. Omega, 2016, 62(01):115-122.

[4] Bai Hao. Research on conflict and pricing of mixed dual-channel fresh produce supply chain[J]. Logistics Technology,2019,38(05):93-100+121.

[5] Tang R. Dual-channel supply chain coordination for fresh food considering time and temperature factors [J]. China Management Science,2017,25(10):62.

[6] Zhang Xiao. Dual-channel supply chain coordination of fresh produce considering retailers' equity concerns under freshness cost sharing[J]. Industrial Engineering and Management,2021,26(02):15-22.

[7] Peng YY. Fresh food dual-channel supply chain coordination considering time factor [J]. China Management Science,2017,25(10):71.

[8] Blackburn J. Supply chain strategies for perishable products: the case of fresh produce [J]. Production and Operations Management,2009,18(2):129-137.

ISSN: 2692-7608 DOI: 10.6981/FEM.202403_5(3).0007

[9] Fan Linbang. Research on dual-channel supply chain coordination of fresh agricultural products in e-commerce environment[J]. Rural Economy,2019(06):137-144.

[10] Jiang Jia ke. Research on fresh agricultural products dual-channel supply chain coordination and benefit distribution[D]. Beijing Jiaotong University,2019.