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Data Analysis and Risk in Supply Chain Management

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Keywords: Supply chain management, short lifecycle food, supply and demand uncertainty risk, risk sharing, data analysis

Abstract: Life-cycle foods (such as soy products, dairy products, and bread) face dual supply and demand uncertainties in the supply chain due to long production lead times, short sales cycles, and large demand fluctuations. This study constructs a three-tier supply chain model with uncertain supply and demand for short-life-cycle foods, integrates data analysis and risk control methods, and quantifies the risk transmission path. The study finds that under decentralized decision-making, demand uncertainty leads to a reduction in retailer ordering quantity, which in turn triggers a decrease in supplier production, resulting in significantly lower supply chain profits compared to centralized decision-making levels. A single coordination contract (such as a manufacturer-led buy-back contract or a retailer-led option contract) can incentivize retailers to increase ordering quantity through the buy-back price or option mechanism, achieving Pareto improvement in the supply chain. When considering supply uncertainty, a combination contract is designed for both supplier and manufacturer alliances (where the retailer bears the alliance's raw material procurement costs and the alliance provides buy-back subsidies) and non-alliance (where the supplier and manufacturer jointly subsidize the retailer and share each other's costs), which can achieve shared supply and demand risks, enhance the profits of alliance members, and optimize overall revenue distribution. In management practice, retailers need to choose options or buy-back contracts based on their own bargaining power to reduce demand risks; when the manufacturer leads, excess products can be bought back to incentivize ordering, and when the retailer leads, mutually beneficial contracts need to be developed through cooperation; suppliers need to participate in risk sharing or form alliances with manufacturers to enhance efficiency and risk prevention capabilities.

1 Introduction

Short life cycle foods (such as soy products, dairy products, bread) have become a key category for upgrading consumer structure due to long production lead times, short sales cycles, and large demand fluctuations. However, they also face supply chain supply and demand uncertainty risks - natural factors (temperature, water sources, light) lead to fluctuations in raw material supply, and market factors (brand competition, price changes) trigger demand uncertainty. Although the improvement of cold chain logistics and transportation infrastructure enhances temporal and spatial efficiency, the dual uncertainty of supply and demand places higher demands on the resilience of the supply chain. It is necessary to achieve risk sharing through cooperation contracts and alliance mechanisms, and promote the transformation of the supply chain from individual competition to inter chain collaboration. There are significant challenges in existing research: traditional literature often focuses on a single uncertain dimension (demand or supply) in the secondary supply chain, and there is limited exploration of the transmission mechanism and coordination strategies for the dual uncertainty of supply and demand in the tertiary supply chain; The perishability and low residual value characteristics of short life cycle foods [1] have not been fully incorporated into the risk model, resulting in a lack of targeted contract design; In the scenario of multi-level supply chain, data-driven dynamic matching methods still need to be deepened, and the effectiveness verification of existing contracts in uncertain supply and demand scenarios is insufficient.The motivation for this study stems from filling theoretical gaps and practical needs, quantifying the transmission path of supply and demand uncertainty risks in the three-level supply chain through data analysis, and designing a risk sharing mechanism[2] to achieve coordination. The objectives include revealing the impact of supply and demand uncertainty on decision-making, constructing a dynamic matching contract design framework, and verifying the effectiveness of the mechanism in profit distribution and efficiency improvement. The contribution is reflected in three aspects: innovating the three-level supply chain risk sharing model at the theoretical level and incorporating short lifecycle characteristics; Propose data-driven dynamic matching strategies at the methodological level to optimize supply chain resilience; At the practical level, provide operational cooperation mechanisms and decision-making tools for enterprises to promote sustainable value creation. A research review shows that supply chains with uncertain supply and demand have covered scenarios such as Cournot competition, pricing strategies, and inventory optimization, but the combination of multi-level supply chains and short lifecycle characteristics still needs to be expanded. Representative studies include: supply chain centralization in high supply uncertainty or low competitive environments dominates under demand uncertainty scenarios (Fang&Shou, 2015); Commercial insurance can avoid the risk of raw materials for agricultural and sideline products in uncertain supply scenarios (subject to specific conditions) (Chen Jing et al., 2018); The combination mechanism of repurchase and subsidy under dual uncertainty of supply and demand can achieve Pareto improvement (Fu et al., 2017); Coordination efforts in the three-level supply chain can quantify decision-making and optimize production and inventory (Hsieh et al., 2008). This study integrates data analysis and risk management methods to promote dynamic matching and value reassessment of short lifecycle food supply chains in uncertain scenarios, providing a new perspective for data analysis and risk research in supply chain management.

2 Correlation theory

2.1 Risk and Uncertainty Analysis of Short Life Cycle Food Supply Chain

Short life cycle foods [3] refer to foods with long production lead times, short sales cycles, low residual value at the end of sales, and large demand fluctuations, such as soy products, dairy products, bread, cakes, etc. Its characteristics include: high consumer demand and fierce market competition, perishable nature resulting in shelf life usually only a few days to weeks, requiring flexible management and marketing strategies in the supply chain; The raw materials are mostly fresh crops, with a simple and fast processing flow, minimal addition of preservatives, and reliance on cold chain transportation and refrigerated storage to extend shelf life and preserve nutrients. However, they are easily affected by environmental factors and are prone to spoilage. Suppliers, manufacturers, and retailers are required to make efforts and costs to preserve freshness and sell as soon as possible to avoid waste. Risk definition [4] refers to the uncertainty between production objectives and labor outcomes, which has three major characteristics: accompanied by uncertainty and unpredictability, it is difficult to accurately control future risks; There is a potential loss nature that may lead to negative impacts such as the breakage of the company's financial chain, a decrease in profits, or damage to personal reputation; Incomplete information leads to insufficient decision-making basis, making it difficult to predict and quantify unknown factors such as policy changes, market fluctuations, and natural disasters. Uncertainty refers to all situations where the outcome is unknown, which is reflected in the short life cycle food supply chain as uncertainty in raw material supply (production may meet or be short) and market demand (which may be greater or less than the order quantity leading to stockouts or excess losses). Dynamic matching and resilience optimization need to be achieved through data-driven risk analysis.

2.2 Supply Chain Coordination and Theoretical Framework

Supply chain coordination [5] achieves multi-party collaboration among suppliers, manufacturers, distributors, consumers, etc. through contract design, information sharing, incentive measures, and pricing strategies, optimizing resource allocation and information flow, and maximizing the interests of both supply and demand sides. The obstacles include information transmission, operation, incentives, pricing, and behavioral barriers, while management leverage involves information sharing, operational performance improvement, goal consistency incentives, pricing strategy design, and trust mechanism establishment. Contract theory, as an economic tool, studies the role of contracts in economic activities, especially in scenarios of information asymmetry[6]and risk sharing. Through the three links of design, execution, and dispute resolution, it regulates behavior, reduces coordination costs, and improves efficiency and competitiveness. Pareto optimization emphasizes improving the overall profitability of the supply chain without harming the interests of any members through precise resource allocation and innovative management on the basis of existing profits. It is an effective management tool under limited resources. The expected utility theory is applied to uncertain decision-making, combined with probability and preference evaluation of expected utility. It is widely used in financial investment, enterprise management, and consumer behavior analysis, helping rational decision-making as shown in Table 1

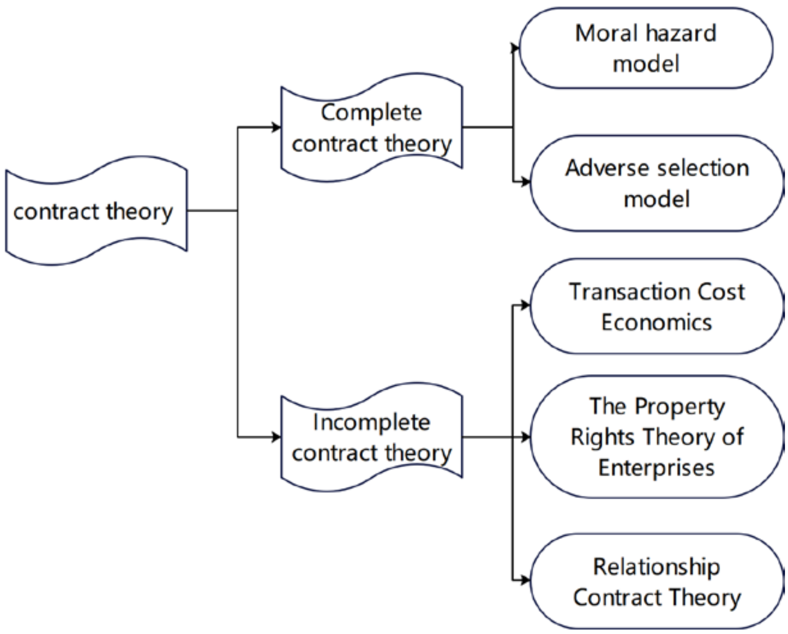

Figure 1 Development of Contract Theory

Based on the above theory, this article constructs a three-level short life cycle food supply chain model, designs repurchase contracts, option contracts, and combination contracts to achieve risk sharing, and combines Pareto optimization objectives and expected utility theory to verify the effectiveness of the mechanism through numerical analysis, promoting supply chain coordination and revenue improvement.

3 Research method

3.1 Risk and Decision Model of Short Life Cycle Food Supply Chain

Consumers' high demands for food quality, freshness, delivery speed, and supply stability are contradictory to the dual uncertainty of raw material supply and market demand in the short lifecycle food supply chain. Raw material suppliers are affected by factors such as climate and production conditions, resulting in a gap between planned and actual production, and facing the risk of supply shortages or surpluses; Retailers face uncertain demand risks due to factors such as brand competition and market fluctuations, which can lead to shortages or excess losses. These risks directly affect the profits of supply chain members and require contract design to achieve risk sharing and supply chain coordination. The model constructs a three-level supply chain consisting of suppliers, manufacturers, and retailers: suppliers provide raw materials and face supply uncertainty caused by actual productivity (random variables, following a specific distribution); Manufacturers process and sell to retailers, who are consumers facing uncertain demand caused by market demand (random variables, following a specific distribution). The supply chain operation process includes the supplier setting wholesale prices, the manufacturer making decisions on wholesale prices and order quantities, and the retailer making decisions on finished product order quantities. The parameters include production costs, wholesale prices, order quantities, market demand, actual productivity, etc. Multiple psychological accounts and risk aversion coefficients (reflecting the degree of aversion to losses) are introduced to construct the expected utility function. The key assumptions include: linking the relationship between raw materials and finished products through a "conversion factor"; The price relationship ensures profitability at all stages (such as zero selling price>manufacturer wholesale price>manufacturer cost+supplier wholesale price, supplier wholesale price>its cost+market procurement cost); Market raw material prices are higher than supplier production costs, avoiding manufacturers from completely outsourcing raw materials. This model lays the foundation for analyzing the impact of supply and demand uncertainty risks on the supply chain and designing a risk sharing mechanism.

3.2 Comparison of Short Life Cycle Food Supply Chain Decision Models and Profit Coordination

In the short lifecycle food supply chain, there is a dual uncertainty between raw material supply and market demand, and it is necessary to analyze the decisions and benefits of supply chain members through centralized and decentralized decision-making models. The centralized decision-making model considers suppliers, manufacturers, and retailers as a whole, with risk neutral leaders making unified decisions to maximize expected profits. Its expected profit function includes total cost items such as sales revenue, supplier production costs, and market procurement costs. By verifying the function as a concave function using the Haisai matrix [7], the optimal order quantity Q_ {M} ^ N ^ * and the planned raw material production rate R_S ^ N ^ * satisfy equation1, respectively

$$p(1 - F(Q_M^N)) = kC_m + C_s' + kC_s \qquad \text{(Formula 1)}$$

and the parameter influence relationship shows that Q_S ^ N ^ * increases with the increase of sales price p, and decreases with the increase of manufacturer unit cost C_m and market procurement cost C_s; The value of R_S ^ N ^ * decreases as the unit costC_s of the supplier increases, and increases as C_s' increases. In the decentralized decision-making model [8], each member makes independent decisions to maximize their expected utility, while the supplier considers the risk aversion coefficient

θ , The expected utility function includes a profit account and a loss account. By reverse solving, the optimal order quantity Q_M^{D*} for retailers satisfies the equation $Q_M^{D*} = \frac{p-W_M}{pF'(Q_M^N)}$ and the optimal planned production quantity R_M^{D*} for suppliers satisfies equation 2 $R_M^{D*} = \frac{\int_0^{kQ_M^N} zg(z)dz}{\theta C_s^{"}}$. The parameter influence shows that Q_M^{D*} It increases with the increase of p and decreases with the increase of manufacturer wholesale price WM; RMD * decreases with increasing CS and increases with increasing Cs' and θ . Proposition 5 states that under decentralized decision-making, the profit of the supply chain is lower than that under centralized decision-making, due to the retailer's order quantity QMD *<QMN * leads to a decrease in the manufacturer's order quantity and the supplier's planned production volume, resulting in an overall decline in profits. This difference provides a theoretical basis for designing risk sharing contracts to coordinate supply chains and enhance profits.

3.3 Design of Coordination Mechanism for Short Life Cycle Food Supply Chain

To address the issues of insufficient order quantity and declining supply chain profits for retailers under decentralized decision-making, two coordination mechanisms are designed: manufacturer led repurchase contracts and retailer led option contracts. The repurchase contract[9] is led by the manufacturer, who recovers unsold products from retailers at the end of the season by providing unit repurchase prices, sharing the risk of market demand uncertainty. The order quantity of retailers increases with the increase of sales price and repurchase price, and decreases with the increase of manufacturer wholesale price; The planned output of suppliers decreases with the increase of their own unit production costs, and increases with the increase of market raw material procurement costs and risk aversion. When the repurchase price is adjusted to a specific level, the supply chain profit can reach the optimal level under centralized decision-making, achieving risk sharing and profit enhancement.Option contracts are led by retailers, who lock in products by paying unit option prices and exercise prices to reduce ordering costs and incentivize retailers to increase order quantities. The reserve of retailers increases with the rise of option prices and decreases with the rise of option prices; The pattern of changes in supplier planned production is similar to that of repurchase contracts. When the exercise price is adjusted to a specific level, the supply chain can achieve coordination and drive overall profit growth.Both types of contracts incentivize retailers to increase order quantities to a centralized decision-making level through price parameter adjustments, synchronously driving manufacturers and suppliers to increase planned production, ultimately achieving overall profit improvement and risk sharing in the supply chain.

4 Results and discussion

4.1 Design of supply chain coordination mechanism under uncertain supply and demand risks

In the short lifecycle food supply chain, it is necessary to simultaneously address the dual uncertainty risks of supply and demand. The single contract designed earlier only focuses on the demand risk of retailers and does not involve the supply risk of suppliers, with limited room for profit improvement. Therefore, this chapter designs two types of combination contracts to achieve supply and demand risk sharing and supply chain coordination.One is the risk sharing contract under the alliance between suppliers and manufacturers. The alliance integrates resources, with retailers sharing some of the alliance's out of stock losses and production costs, while the alliance recycles surplus products from retailers at repurchase prices. By adjusting parameters such as sharing ratio and repurchase price, the retailer's order quantity and alliance planned production can reach a centralized decision-making level, promoting the overall profit of the supply chain. Parameter relationship shows that the utility of the alliance increases with the increase of the sharing ratio and decreases with the increase of the repurchase price; The utility of retailers shows the opposite trend.The second is the risk sharing contract between suppliers and manufacturers in the absence of alliances. Retailers, manufacturers, and suppliers each bear their own costs and losses, such as retailers sharing the market procurement costs of suppliers, manufacturers subsidizing retailers' surplus products, etc. By adjusting parameters such as cost sharing ratios and subsidy prices, supply chain coordination can also be achieved. The parameter relationship shows that the utility of suppliers increases with the increase of the sharing ratio between manufacturers and retailers, and decreases with the increase of their own subsidy intensity; The utility of manufacturers and retailers is dynamically influenced by cost sharing and subsidy intensity.Two types of contracts incentivize members to increase their order quantity and planned output through parameter adjustments, ultimately achieving an overall increase in supply chain profits, risk sharing, and benefit sharing.

4.2 Model experiment

Parameter setting: Market demand X follows a normal distribution with a mean of 800 and a standard deviation of 40; The random output rate of raw materials z follows a uniform distribution on [0,1]. The relevant parameters for numerical analysis are detailed in Table 6-1, including unit price, cost, and risk sharing mechanism parameters as follows: p=10， WS=0.2， WM=8.5， CM=3，CS=0.04，CS'=0.1，k=10。 Centralized decision-making model analysis: The total profit of the supply chain is affected by the retailer's order quantity and the supplier's planned production, showing a trend of first increasing and then decreasing. In the optimal state, the retailer's order quantity Q_S ^ {N}=811.2309, the supplier's planned production quantity R_S ^ {N}=9069.8369, and the maximum profit of the supply chain is 4731.0489. Decentralized Decision Model Analysis (θ =1, Supplier Risk Neutral): The optimal order quantity for retailers is QnM ^ {D}=758.5427, with a profit of 1106.7365; Manufacturer's profit is 2654.8993; The optimal planned output of the supplier is R_S ^ {D}=8480.7648, with a profit of 838.6241; The total profit of the supply chain is 4600.2600, significantly lower than the level of centralized decision-making. Repurchase contract coordination model (θ =1): When the repurchase price Mb is in the range of 7.20 to 7.60, the profits of each member are better than those of decentralized decision-making. When Mb=7.54, the retailer's order quantity and the supplier's planned production reach the centralized decision-making level (811.2309, 9069.8369), and the supply chain profit reaches the maximum value of 4731.0486, achieving perfect coordination. The specific data is shown in Table 1.

Profit trend with Mb variation, option contract coordination model (θ =1, Ro=0.95): When the exercise price Re is in the range of 7.53 to 7.58, the profits of each member are better than those of dispersed decision-making. When Re=7.56, the supply chain profit reaches the centralized decision-making level of 4731.0489, achieving perfect coordination. The specific data is shown in Table 2.

Table 1 Profit and Production Data under the Repurchase Contract Coordination Model

Repurchase Price (Mb)	Retailer's Optimal Order Quantity (QM_B*)	Supplier's Optimal Planned Production (RS_B*)	Retailer's Profit (π_R_B)	Manufacturer's Profit (π_M_B)	Supplier's Profit (π_S_B)	Total Supply Chain Profit (π_L_B)
7.60	812.7456	9086.7718	1163.5973	2668.7927	898.5494	4730.9393
7.54	811.1473	9069.8369	1162.2393	2672.0269	896.7824	4731.0486
7.50	810.1339	9057.5722	1161.3657	2673.9634	895.6620	4730.9911
7.40	807.7611	9031.0439	1159.2837	2678.1450	893.0387	4730.4674
7.30	805.5884	9006.7523	1157.3327	2681.5355	890.6366	4729.5049
7.20	803.5857	8984.3612	1155.4976	2684.2847	888.4225	4728.2048

Table 2 Option Contract Coordination Model Profit and Production Data Table

Option Exercise Price (Re)	Retailer's Optimal Order Quantity (QM_T*)	Supplier's Optimal Planned Production (RS_T*)	Retailer's Profit (π_R_T)	Manufacturer's Profit (π_M_T)	Supplier's Profit (π_S_T)	Total Supply Chain Profit (π_L_T)
7.58	810.9059	9066.2037	1138.7914	2695.7369	896.5155	4731.0439
7.57	811.0741	9068.0843	1146.6808	2687.6655	896.7015	4731.0478
7.56	811.2309	9069.8368	1154.0840	2680.0901	896.8748	4731.0489
7.55	811.4070	9071.8060	1162.4615	2671.5164	897.0695	4731.0474
7.54	811.5717	9073.6473	1170.3529	2663.4389	897.2516	4731.0434
7.53	811.7352	9075.4760	1178.2448	2655.3595	897.4324	4731.0368

4.3 Effect analysis

In the supplier manufacturer alliance risk sharing model, when the supplier risk aversion coefficient θ =1.1, the parameter relationship is α =0.0909+0.9091 β , Ub=7.6098+1.3983 β . Within the range of β ∈ [0,0.0364], the profits of all entities are better than the decentralized decision-making model (the total decentralized profits of manufacturers and suppliers are 3493.5234), and the alliance profits are always higher and distributable to ensure the profits of all members. Compared to a single repurchase contract, the profits of retailers under this alliance contract have decreased, but the alliance profits have significantly increased, reflecting the effective sharing of supply uncertainty risks and the increase in profits of alliance members. In the non alliance supply and demand uncertainty risk sharing model, when θ =1.1, Mb=6, and Sb=1.4, ω M+ω R=0.0909, ϕ+ω R=30 × 4.4721+0.3466, γ ∈ [0,0.0343) can ensure that supplier profits are better than decentralized decision-making. As β increases, α and Ub rise, and retailer profits decrease from 1130.8078 to 1097.7295, while alliance profits increase from 3600.2412 to 3633.3194; As ω R increases, ϕ decreases from 0.011554 to 0.002610, with retail profits fluctuating around 1135.4516, manufacturer profits fluctuating around 2717.4827, and supplier profits stabilizing at 878.1145. When γ changes, the retailer's profit remains unchanged, the supplier's profit decreases as γ increases, and the manufacturer's profit increases, achieving revenue adjustment. Each contract achieves Pareto improvement under specific parameters, partially reaching the level of centralized decision-making profit, and further enhancing supplier profits through risk sharing among members.

5 Conclusion

In supply chain management, by constructing a three-level short life cycle food supply chain model with uncertain supply and demand and conducting numerical analysis, it was found that demand uncertainty under decentralized decision-making leads to a decrease in retailer order quantity, which in turn causes a decrease in supplier production, resulting in significantly lower supply chain profits than centralized decision-making levels; Single coordination contracts, such as manufacturer led repurchase contracts and retailer led option contracts, can incentivize retailers to increase order quantities through repurchase prices or option mechanisms, achieving Pareto improvement in the supply chain. When further considering the risk of supply uncertainty, designing a combination contract between supplier and manufacturer alliances (retailers bear the cost of alliance raw material procurement, alliances provide repurchase subsidies) and non alliances (suppliers and manufacturers jointly subsidize retailers and share each other's costs) can achieve supply and demand risk sharing, improve alliance member profits, and optimize overall revenue distribution. In management practice, retailers need to strengthen cooperation with manufacturers and suppliers, and choose options or repurchase contracts based on their own discourse power to reduce demand risks; When the manufacturer takes the lead, they can repurchase excess products to incentivize ordering, while when the retailer takes the lead, they need to cooperate to develop mutually beneficial contracts; Suppliers need to participate in risk sharing by contracting other members to bear supply risks, or forming alliances with manufacturers to improve efficiency and risk prevention capabilities. Future research can introduce a mechanism for sharing the efforts of preservation in various links of the supply chain [10], and study the cost sharing of preservation in the three-level supply chain; Construct a more realistic market demand function based on the characteristics of the decline in the value of short lifecycle food over time; Considering the impact of consumer freshness sensitivity on demand, deepening research on risk sharing in uncertain supply and demand, and providing more accurate data analysis and risk control strategies for supply chain management.

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