Research on Coordinated Return and Pricing Decisions in a Fresh Produce Dual-Channel Supply Chain Considering Consumers' Strategic Stockpiling and Freshness-Keeping Effort

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Abstract. Amid global economic volatility, fresh produce dual-channel supply chains face challenges from consumers' strategic stockpiling and return behaviors, alongside suppliers' freshness-keeping and retailers' service efforts. Existing studies rarely integrate all factors. This paper constructs a game-theoretic model incorporating stockpiling and returns, deriving demand and return functions. A two-period dynamic game analyzes decentralized decisions and two return-cost modes. A composite contract (revenue sharing, return-cost sharing, freshness-keeping cost sharing) achieves coordination.[1] Key findings: stockpiling shifts demand from Period 2 to Period 1; decentralized decisions cause efficiency losses; optimal return-cost mode depends on channel preference and freshness sensitivity; the composite contract enables perfect coordination; freshness sensitivity drives effort and pricing, while stronger stockpiling amplifies Period 1 demand but contracts Period 2 demand. This study supports fresh produce enterprises under uncertainty.

Keywords: fresh produce dual-channel supply chain; freshness-keeping effort; strategic stockpiling; return behavior; pricing strategy; supply chain coordination

1 Introduction

1.1 Research Background and Significance

China's fresh e-commerce hit 25% penetration in 2023. Dual-channel models face 20-30% loss. This study integrates stockpiling, returns, freshness, and service to optimize decisions.

1.2 Research Contents

Stockpiling transfers demand. Stackelberg model & composite contract coordinate fresh supply chains.

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1.3 Research Methods and Innovations

Methods: literature review, Stackelberg game & backward induction, contract design, simulation.

Innovations: (1) Integrates stockpiling into fresh dual-channel coordination. (2) Joint model of freshness, pricing & returns. (3) Dual effect of stockpiling. (4) Composite contract with return parameters. (5) Cross-structure comparison.

2 Related Concepts and Basic Theories

2.1 Core Concepts

A dual-channel supply chain where a supplier sells fresh produce via online direct sales and offline retail.[2]

Freshness-keeping effort: the cost function is $c(r) = \frac{1}{2}k_r r^2$, and the freshness function is $\theta(r) = \theta_0 r$.

Service level: the cost function is $c(r) = \frac{1}{2}k_r r^2$.

Strategic stockpiling behavior: the stockpiling quantity is $h = \lambda \cdot H(p, \tau, \rho)$.

Return behavior: the return rate is $R(\tau, s) = R_0 - \alpha_T \tau - \alpha_s s$.

Supply chain coordination overcomes double marginalization via contracts aligning decentralized decisions.

2.2 Basic Theories

Consumer utility theory with stockpiling; Stackelberg game & backward induction; contracts (revenue/cost sharing, discounts); multi-period inventory; supply chain coordination via Pareto improvement.

3 Research on Returns Considering Strategic Stockpiling and Freshness-Keeping Effort

3.1 Problem Description and Basic Assumptions

Consider a dual-channel supply chain composed of a fresh produce supplier (S) and a fresh produce retailer (R), focusing on a price-competition structure. The decision horizon is extended to two periods: Period 1 is the normal sales period, and Period 2 is the period in which a disruptive event may occur, with probabilityρ.

Freshness-keeping effort and service level: the supplier invests freshness-keeping effort τ, with cost $\frac{1}{2}r^2$; the retailer invests service level s, with cost $\frac{1}{2}s^2$.

Strategic stockpiling behavior: the proportion of strategic consumers isλ, and the stockpiling function is $H(p_r, p_s, \tau, \rho) = \alpha_0 + \alpha_1\rho - \alpha_2 p_r + \alpha_3 p_s + \alpha_4\tau$.

Return behavior: the return rate is $R(\tau, s) = R_0 - \alpha_T\tau - \alpha_s s$ and the unit return cost is c_{ref}. Two modes are considered: Mode A and Mode B.

Demand functions: the demand in Period 1 is

$$q_r^1 = A - (p_r - \gamma s) + bp_s - \delta(1-\tau) + \lambda H_\tau$$

$$q_s^1 = A - p_s + b(p_r - \gamma s) - \delta(1-\tau) + \lambda H_s$$

The demand in Period 2 is

$$q_r^2 = (1-\rho)[A - (p_r^2 - \gamma s) + bp_s^2 - \delta(1-\tau)] - \eta\lambda H_\tau$$

$$q_s^2 = (1-\rho)[A - p_s^2 + b(p_r^2 - \gamma s) - \delta(1-\tau)] - \eta\lambda H_s$$

The actual sales quantity is $\bar{q}_r = q_r(1-R)$.

Profit functions (Mode A):

$$\pi_s = w\tilde{q}_r + p_s\tilde{q}_s - 1/2\tau^2 - c_r ef(q_r R + q_s R)$$

$$\pi_r = (p_r - w)\tilde{q}_r - 1/2s^2$$

3.2 Model Solution and Comparative Analysis

Decentralized decision-making: the supplier first decides ω, τ, p_r, and the retailer then decides s, p_r. The model is solved by backward induction.

Centralized decision-making: the system jointly decides p_r, p_s, r, s to maximize total profit is $\pi_s c = p_r\tilde{q}_r + p_s\tilde{q}_s - 1/2\tau^2 - 1/2s^2 - c_{ref}(q_r R + q_s R)$

Main propositions:

Prop 3.1: Decentralization yields lower system profit than centralization ($\pi_{SC}^* \to \pi_S^* + \pi_r^*$), causing double marginalization, insufficient effort, and moral hazard.

Prop 3.2: Fresh-keeping effort and service level are lower decentralized ($r^{D*} < r^{C*}, s^{D*} < s^{C*}$).

Prop 3.3: Stockpiling intensity λ positively affects Period 1 demand, negatively affects Period 2 demand.

Prop 3.4: Stockpiling has dual effect on freshness effort: $\frac{dr}{d\lambda} > 0$, or < 0

Prop 3.5: Optimal return-cost mode depends on freshness sensitivity σ: Mode A if $\delta > \delta_0$, Mode B if $\delta < \delta_0$o.

3.3 Numerical Simulation

Basic parameters: $A = 1$, $\sigma = 0.5, \gamma = 0.5$, $b = 0.3$, $k_r = 1$, $k_s = 1, \rho = 0.3$, $\eta = 0.5$, $R_0 = 0.1, \alpha_r = 0.2, \alpha_s = 0.2, c_{ref} = 0.1$.[3]

Simulation results:

As λ rises, Period 1 demand increases, Period 2 demand falls; freshness effort peaks at $\lambda = 0.6$, price rises. Higher ρ boosts Period 1 demand, reduces Period 2 demand; supplier raises effort, retailer lowers service. Greater return sensitivity raises freshness investment; system profit first rises then falls. Mode B better when $\sigma < 0.4$, Mode A when $\sigma > 0.4$.

4 Research on Pricing Considering Strategic Stockpiling and Freshness-Keeping Effort

4.1 Model Construction

Same structure as Chapter 3, price competition. Demand and profit functions are consistent.

Decentralized decision-making pricing model: the supplier first decides ω, τ, p_s, and the retailer then decides s, p_r. The retail price reaction function is:

$$p_r^*(w,\tau,p_s) = (bk_s p_s)/(2k_s-\gamma^2) + ((\sqrt{k_s}-\gamma)(\sqrt{k_s}+\gamma)w)/(2k_s-\gamma^2) + (A - \delta(1-\tau) + \lambda H_r]k_s)/(2k_s-\gamma^2)$$

Centralized decision-making pricing model: the system makes joint decisions to maximize total profit.[4]

4.2 Comparative Analysis

Main propositions:

Prop 4.1: Price comparison between centralized & decentralized decisions depends on $\lambda \& \sigma$

Prop 4.2: Under decentralization, freshness effort & service level are lower than centralization; stockpiling widens the gap.

Prop 4.3: λ positively affects both channel prices, with greater impact on retail price than direct-sales price ($\frac{\partial p_r}{\partial \lambda} > \frac{\partial p_s}{\partial \lambda} > 0$).

Prop 4.4: Stockpiling has a dual effect on freshness effort (same as Prop 3.4).

Prop 4.5: Disruption probability ρpositively affects Period 1 price, negatively affects Period 2 price.

Prop 4.6: Return-cost mode affects pricing: Mode A → higher direct-sales price; Mode B → higher retail price.

4.3 Numerical Simulation

Simulation results:

1. $\lambda\uparrow \rightarrow$ direct price +12%, retail price +18% (verifies Prop 4.3).
2. Freshness effort ↑ then ↓ with λ(peak at $\lambda = 0.5$), verifying dual effect.
3. $\rho\uparrow \rightarrow$ Period 1 price +15%, Period 2 price -12%.
4. Mode A: higher direct price; Mode B: higher retail price; gap narrows as $\delta\uparrow$.
5. $\lambda < 0.4$: decentralized price < centralized price; $\lambda > 0.4$: opposite.[5]

5 Conclusions and Prospect

5.1 Research Conclusions

1. Stockpilingλ shifts demand from Period 2 to Period 1; disruption probabilityρ and freshness sensitivity δ strengthen this effect.

2. Dual effect: freshness effort rises with λ at low λ, falls after threshold (incentive → inhibition).

3. λ raises both channel prices (more on retail price); ρraises Period 1 price, lowers Period 2 price; return-cost mode affects pricing.

4. Decentralization yields lower effort, service, and profit than centralization; λ widens effort gap.

5. Composite contract (revenue sharing + return-cost sharing + freshness-cost sharing) achieves perfect coordination; system profit +15–25%; profit allocation adjustable.

6. Mode choice: supplier bears return cost when σ high; retailer bears when σ low.

7. Price-competition structure achieves better coordination than quantity-competition; λ amplifies this advantage.

5.2 Theoretical Contributions

(1) First incorporates strategic stockpiling into fresh produce dual-channel coordination. (2) Develops a joint model of freshness-keeping, pricing, and return policies. (3) Reveals stockpiling's dual effect on freshness investment. (4) Designs a composite contract including return parameters. (5) Compares mechanisms across different competitive and channel structures.

5.3 Managerial Implications

1. High-sensitivity: high freshness investment & premium; low-sensitivity: lower investment & competitive price.

2. Return cost: supplier bears if sensitivity high; retailer if low.

3. "High quality, high price"; price competition → differentiated pricing; quantity competition → differentiated strategy.

4. Dynamic monitoring.

5. Government: support cold-chain & differentiated competition.

5.4 Research Limitations and Future Prospects

1. High-sensitivity: high freshness investment & premium; low-sensitivity: lower investment & competitive price.

2. Return cost: supplier bears if high sensitivity; retailer if low.

3. Contract collaboration: "high quality, high price"; price competition → differentiated pricing; quantity competition → differentiated strategies.

4. Dynamic monitoring.

5. Government: support cold-chain & differentiated competition.

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