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The Partial Centralization Decision for ClosedLoop Supply Chain Coordination with Trade-In Strategy

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Abstract: To explore the impact of partial centralization on supply chain performance, this study constructs a two-period game model of a closed-loop supply chain involving a manufacturer and an online retail platform participating in the trade-in strategy. Through mathematical modeling and numerical simulation methods, the optimal decisions were analyzed under conditions where the manufacturer partially owns the retail platform's partial equity. This study finds that partial centralization yields the highest profits, followed by full centralization, with decentralized decisions yielding the lowest profits. Moderate centralization enhances overall profits by optimizing incentive mechanisms, whereas excessive ownership concentration reduces the flexibility of the retail platform, leading to a decline in profits. Additionally, product durability and trade-in subsidy significantly influence supply chain profitability: high-durability products reduce renewal frequency, while trade-in subsidy effectively stimulates consumer demand and increase overall profits. This study provides theoretical support and practical guidance for companies implementing the trade-in strategy.

Keywords: Closed-loop supply chain; Coordination; Partial centralization; Trade-In

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1. Introduction

In 2024, the State Council of China issued the "Action Plan for Promoting Large-Scale Equipment Upgrades and Trade-In Programs for Consumer Goods", thereby launching a new round of trade-in initiatives aimed at stimulating domestic demand and advancing green transformation. The plan particularly encourages the replacement of high-value durable goods such as new-energy vehicles and electronic products. Trade-in programs are closely related to the closed-loop supply chain (CLSC), which manages the full product lifecycle, from design and production to use, recycling, and remanufacturing, and serves as a vital mechanism for resource circulation and product reuse [1].

In the implementation of trade-in initiatives, two problems are critical: on the demand side, providing incentives and constraints to encourage consumers to return used products; and on the supply side, achieving coordination and governance among manufacturers, online retail platforms, and recycling actors.

The existing literature on trade-in primarily examines firms' adoption decisions, the design of pricing and subsidy schemes, and the choice of implementation models. Studies compare organizational structures such as centralized recycling, retailer-led recycling, and manufacturer-led recycling, and further analyze how second-hand and peer-to-peer (P2P) markets affect pricing, product quality, and intertemporal decisions [2–5]. In parallel, the supply chain governance literature has long focused on the efficiency trade-offs between centralization and decentralization [6]. More recently, research highlights "partial centralization" typically established through equity participation, as a hybrid governance mode that facilitates information sharing and coordination [7,8]. In particular, Li et al. developed a multi-period dynamic model encompassing centralized, decentralized, and partially centralized supply chains, providing a unified analytical framework for comparing these governance structures [9].

Against this backdrop, this paper investigates the collaborative decision-making problem between a manufacturer and an online retail platform under a trade-in program. This study constructs a two-period game-theoretic model, where the manufacturer's equity stake in the platform captures the degree of partial centralization. Within the settings of full centralization, full decentralization, and partial centralization, we derive the optimal pricing and ordering strategies of both parties and compare supply chain performance. Furthermore, product durability, the intensity of trade-in subsidies, and the presence of a second-hand market are incorporated into the unified framework to examine their joint effects on pricing, recycling, and ordering decisions.

2. Model description and assumption

This study considers a two-period game model in CLSC involving a manufacturer and an online retail platform, both participating in a trade-in program. The manufacturer holds a share of ownership in the platform, denoted by θ. The platform transfers a proportion of its profit to the manufacturer based on θ, where $\theta = 0$ represents a fully decentralized structure and $\theta = 1$ indicates full centralization.

The manufacturer is responsible for the production of new products, with products durability denoted by δ ($0 < \delta < 1$). The online retail platform is responsible for retail sales and the execution of the trade-in in the second period, including the collection and remanufacturing of returned products. Scenarios *C, D* and *P* represent fully decentralized, fully centralized, and partially centralized decision-making structures, respectively. For simplicity, manufacturer profit from remanufacturing, production cost, and discount rates are set to zero [10].

Assuming rational consumers, their utility from new and remanufactured products varies. In a two-period model, each consumer's valuation v for new products is uniformly distributed over [0,1], with the market size normalized to 1. First-period buyers may continue using the product or participate in the trade-in program.

Consumer behavior is classified as follows:

(1) BH: buy in the first period and keep in the second;

(2) BR: buy in the first period and trade in the second;

(3) NB: skip the first period and buy in the second;

(4) NN: no purchase in either period.

It is assumed that the retail platform offers products in both periods and that consumers choose the option maximizing their total utility. The decision sequence follows:

(1) The manufacturer first determines the wholesale prices w_t, $t \in [1,2]$;

(2) The online retail platform determines the order quantities q_t, $t \in [1,2]$ and the trade-in quantity q_3

Based on the solution approach used by Li et al., he inverse demand functions for both periods can be expressed as follows (1)–(3) [9]:

$$p_1 = 1 - q_1 + b \quad (1)$$

$$p_2 = 1 - q_1 - q_2 \quad (2)$$

$$p_3 = (1 - \delta)(1 - q_3) \quad (3)$$

b is the subsidy for the trade-in product, i.e., the residual value.

Since the manufacturer holds a partial ownership share in the online retail platform, a proportion of the platform's profit is transferred to the manufacturer accordingly. In the second period, the profits of the retail platform and the manufacturer are given by (4),(5):

$$\pi_{R2} = (1 - \theta)[(p_2 - w_2)q_2 + (p_3 - w_2)q_3] \quad (4)$$

$$\pi_{m2} = w_2(q_2 + q_3) + \theta\{q_3[(\delta - 1)(q_3 - 1) - w_2] - q_2(q_1 + q_2 + w_2 - 1)\} \quad (5)$$

The retail platform, the manufacturer and supply chain system' profits are given by (6)–(8):

$$\pi_m = \pi_{m1} + w_1 q_1 + \theta(1 - q_1 + b - w_1)q_1 \quad (6)$$

$$\pi_r = \pi_{r1} + (1 - \theta)(p_1 - w_1)q_1 \quad (7)$$

$$\pi^i = \pi_m + \pi_r \quad (8)$$

3. Equilibrium results and analysis

3.1. Equilibrium results

This study adopts the method of backward induction and verifies the negative definiteness of the Hessian matrix to derive the equilibrium solutions under centralized, decentralized, and partially centralized decision-making scenarios. To ensure that the decision variables are strictly positive, the relevant parameters must satisfy the following conditions: $0 < b \leq 0.675$.

(1) Proposition 1:

(i) Under centralized decision-making, the equilibrium solution:

$$q_1^c = (1 + 2b) / 3; \; q_2^c = (1 - b) / 3; \; q_3^c = 0.5;$$

(ii) The profit of the supply chain system under centralized decision-making:

$$\pi^c = [7 + 4b(1 + b) - 3\delta] / 12;$$

(2) Proposition 2:

(i) The overall profit of the supply chain under decentralized decision-making:

$$w_1^D = \frac{1}{112}\left[95 + 52b + \frac{63}{-2+\delta} - \frac{24(-1+b)}{-13+7\delta}\right], \; w_2^D = \frac{[47 + 4b(-2+\delta) - 25\delta][1-\delta]}{4(-2+\delta)(-13+7\delta)}, \; q_1^D = \frac{-5 + 4b(\delta - 2) + 3\delta}{-26 + 14\delta},$$

$$q_2^D = \frac{1}{56}\left[-3 - 4b - \frac{21}{-2+\delta} + \frac{32(b-1)}{-13+7\delta}\right], \; q_3^D = \frac{1}{8}\left[4 + \frac{3}{\delta - 2} - \frac{4(b-1)}{-13+7\delta}\right];$$

(ii) The profit of the supply chain system under decentralized decision-making:

$$\pi^D = \frac{(43\delta - 79)[2b(\delta - 2) + (3\delta - 5)]b}{8(13 - 7\delta)^2} + \frac{\delta\{20293 + \delta[(5651 - 784\delta)\delta - 15793]\} - 10087}{64(13 - 7\delta)^2(\delta - 2)};$$

(3) Proposition 3:

(i) Under partial centralization, the equilibrium solution:

$$w_1^P = \frac{(\theta-1)\{A_5 + A_2\,[A_4 - 25 - 7\,(\theta-4)\,\theta + \delta\,[13 + 4\,(\theta-4)\theta]]\}}{[2\,(\delta-2)\,(\theta-2)^2\,A_1]},\ q_1^P = \frac{10 - A_2 + 4\,(\theta-3)\theta + \delta\,[(8-3\theta)\theta-6]}{A_1},$$
$$w_2^P = \frac{(\delta-1)(\theta-1)(94 + A_2 + A_6)}{(\delta-2)(\theta-2)\,A_1},\ q_2^P = \frac{74 - A_2\,(\delta+\theta-3) + A_3}{2\,(\delta-2)(\theta-2)\,A_1},\ q_3^P = \frac{114 + A_2(\theta-1) - 2\theta\,[92 + \theta\,(9\theta-50)] + A_1}{2\,(\delta-2)(\theta-2)\,A_1};$$

(ii) Under partial centralization, the total profit of the supply chain:

$$\pi^{\mathrm{P}} = \frac{1}{4\,(-2+\delta)\,(-2+\theta)^2}\{(\theta-1)[4 + \delta\left(-4 + \delta\,(-2+\theta)^2\right) - \frac{3A_9}{A_1^2}] - \frac{A_8}{A_1}\}.$$

Due to space limitations, the values of the parameters A_1-A_9 and the calculation process of the inference results are provided below.

3.2. Analysis

The analysis of the equilibrium results are as follows:

(1) Corollary 1:

(i) $q_1^D < q_1^C$;

(ii) When $0 < \delta < \dot{\delta}$, $q_2^D < q_2^C$;

(iii) $q_3^D < q_3^C$, where $\dot{\delta} = \frac{3\,(-29+26b)}{-65+44b} - 2\sqrt{\frac{316-116b+25b^2}{(-65+44b)^2}}$;

Under centralized decision-making, the retail platform's orders for both phases and trade-in volumes are higher than under decentralized systems. Centralization enhances supply chain efficiency by aligning manufacturer and retail platform decisions, improving demand forecasting, enabling more rational ordering, and supporting more attractive trade-in subsidies, which boost consumer participation and second-phase recovery. Thus, the coordination and information sharing in centralized decision-making result in higher product orders and trade-in volumes compared to decentralized systems.

(2) Corollary 2:

(i) $q_2^i + q_3^i > q_1^i$, I ∈ {C, D, P};

(ii) $w_1^i > w_2^i$, i ∈ {D, P};

Across all decision-making structures, second-phase products have lower wholesale prices but higher total orders than first-phase products, driven by reduced durable-goods pricing and the trade-in program, which lowers consumers' net cost and boosts demand. As a result, second-phase products gain a pricing advantage, significantly increasing overall order volume.

(3) Corollary 3: $\pi^C > \pi^D$;

The profits of centralized decision-making exceed the decentralized decision-making. When the manufacturer and the retail platform make decisions together, they can coordinate activities across all stages, thereby optimizing the overall performance of the supply chain. For example, the manufacturer can set wholesale and retail price based on market demand and production costs, while the retail platform can correspondingly adjust order quantities and the promotional strategy.

(4) Corollary 4: $\frac{\partial w_1^P}{\partial b} > 0$, $\frac{\partial q_1^P}{\partial b} > 0$, $\frac{\partial w_2^P}{\partial b} < 0$, $\frac{\partial q_2^P}{\partial b} < 0$, $\frac{\partial q_3^P}{\partial b} > 0$;

Old-product subsidies create expectations of future rebates through the trade-in, lowering consumers' effective replacement costs and stimulating first-phase demand. This allows manufacturers to raise wholesale prices and retail platform to increase orders. In the second phase, higher trade-In prompt the manufacturer and retail platform to reduce wholesale prices to accelerate turnover and prevent excess inventory. The coordinated subsidy approach strengthens supply chain coordination, enhances competitiveness, and leverages economies of scale.

(5) Corollary 5:

(i) $\frac{\partial w_1^P}{\partial \theta} < 0$, $\frac{\partial w_2^P}{\partial \theta} < 0$, $\frac{\partial q_1^P}{\partial \theta} > 0$, $\frac{\partial q_3^P}{\partial \theta} > 0$;

(ii) If $0.4 < \delta \leq 0.75$, $\frac{\partial q_2^P}{\partial \theta} > 0$;

As ownership increases, wholesale prices for new products in both phases decrease, while first-phase orders for new and trade-in items rise. When product durability exceeds a threshold, second-phase new-product orders also increase, reflecting the residual value that attracts consumers who delay purchases. Greater ownership enables the manufacturer to lower prices, stimulate demand and trade-in participation, and align pricing, subsidies, and supply-chain operations, thereby expanding market volume and boosting second-phase orders. Firms could prioritize durable designs and adjust ownership levels to optimize market strategies.

(6) Corollary 6: $\frac{\partial w_1^P}{\partial \delta} > 0$, $\frac{w_2^P}{\partial \delta} > 0$, $\frac{\partial q_1^P}{\partial \delta} < 0$, $\frac{\partial q_2^P}{\partial \delta} > 0$, $\frac{\partial q_3^P}{\partial \delta} < 0$;

Wholesale prices for new products in both phases rise with durability, yet first-phase and trade-in order quantities decline, while second-phase orders increase. Enhanced durability raises perceived value and justifies premium pricing, causing consumers to retain the first stage purchases longer, reducing immediate replacements but later driving demand for high-quality durable goods in the second stage.

4. Numerical simulation

This section uses Mathematica for numerical simulations to examine how product durability, ownership level, and rebate rate affect decisions and profitability, with non-negativity constraints and the following parameter settings: $b = 0.4$, $\theta = 0.5$, $\delta = 0.45$.

Through numerical simulation, supply chain profits rank as follows: $\pi^P > \pi^C > \pi^D$.

Under partial centralization, profit sharing and retained autonomy encourage platform investment and flexibility, while lower coordination costs enhance efficiency. Full centralization removes double marginalization and gains scale economies but reduces flexibility and may raise coordination costs. Decentralization, hindered by conflicting goals and information asymmetry, yields the lowest profits.

As shown in **Figure 1**, under partial centralization, supply chain profit follows an inverted-U pattern with ownership level: moderate ownership enhances alignment and coordination, improving pricing and ordering efficiency, whereas excessive ownership erodes autonomy, slows response, and raises coordination costs, reducing profits.

As shown in **Figure 2**, greater product durability negatively affects profitability. Longer usage reduces demand for new products and trade-ins, lowering orders and recovery volumes. Although higher prices may signal better quality, weaker demand offsets these gains and narrows margins. Increased durability also prolongs replacement cycles and slows market turnover, further suppressing profitability.

From **Figure 3**, trade-in subsidies enhance supply chain profits across all decision structures, with larger subsidies yielding higher gains. By reducing consumers' purchase costs, subsidies boost demand and order volumes, lower wholesale prices, and improve competitiveness. Increased orders raise revenues for both parties, while greater trade-in participation enhances recovery and remanufacturing, thus improving resource utilization and overall profitability.

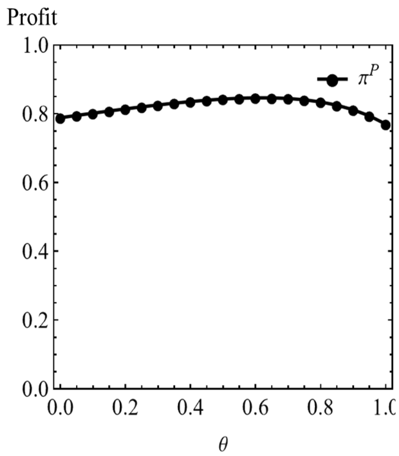

Figure 1. Effect of ownership level on profit.

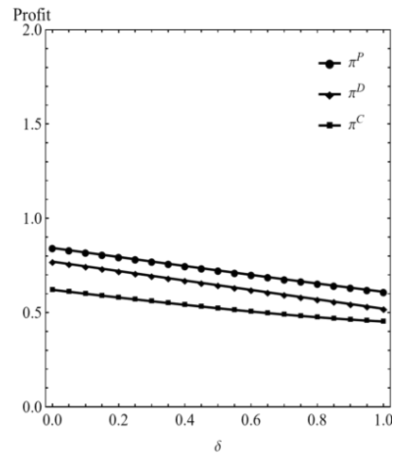

Figure 2. Effect of product durability on profits of supply chain member.

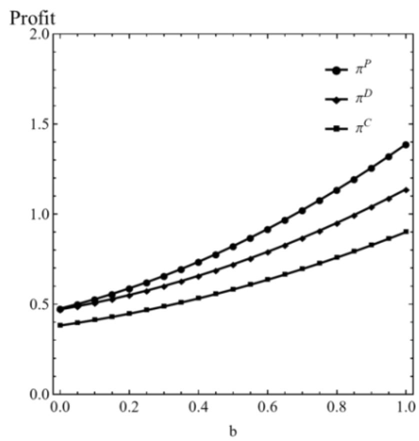

Figure 3. Effect of oldproduct subsidies on of supply chain member.

5. Conclusion

This study develops a two-period game-theoretic model of a closed-loop supply chain in which a manufacturer and an online retailer jointly operate a trade-in program, and compares system performance under decentralized, partially centralized, and fully centralized decision structures. The results show that partial centralization achieves superior outcomes by balancing coordination efficiency with retailer autonomy: at moderate ownership levels, it maximizes overall profit, whereas excessive ownership reduces platform flexibility and responsiveness, leading to profit decline. Product durability exerts a negative effect on profitability, while higher durability signals better quality, it extends replacement cycles and suppresses demand, thereby reducing system revenue. In contrast, old-product subsidies stimulate consumer purchases by lowering effective prices, expanding orders and trade-in participation, and ultimately improving both resource utilization and supply chain profit.

This study offers several managerial insights for firms implementing trade-in strategies. Manufacturers should balance product durability and replacement demand, adopt moderate equity participation, and coordinate dynamic subsidy and pricing strategies. Retailers should enhance responsiveness and collaboration to improve performance. Limitations include simplified assumptions, exclusion of third-party recyclers, and a two-period scope; future work should consider realistic costs and multi-stage dynamics.

Disclosure statement

The author declares no conflict of interest.

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