Equilibrium Pricing in Partially Integrated-Direct (PID) Closed Loop Dual channel Supply Chains (CLDSC) Under Symmetric and Asymmetric Information

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Abstract

Manufacturers increasingly adopt direct online channels alongside traditional retail partners, creating a Partially Integrated structure in which the manufacturer and its direct channel operate as one unit while the retailer remains independent. This paper develops an equilibrium pricing model for such a Partially Integrated-Direct (PID) Closed Loop Dual channel Supply Chain (CLDSC) under symmetric and asymmetric information. Using game theoretic approaches—Nash, Stackelberg, Nash bargaining, and profit sharing—selling prices, wholesale prices, buyback prices, sales effort, and collection effort are optimized simultaneously. The manufacturer (integrated with the direct channel) acts as Stackelberg leader, setting wholesale prices and incentives for the independent retailer. Results from numerical simulation and sensitivity analysis reveal that: (1) the Partially Integrated structure balances coordination efficiency and competitive flexibility; (2) cooperative mechanisms significantly outperform non cooperative ones in total profit and environmental performance (total returns), though consumer surplus is lower; (3) asymmetric information reduces profit in cooperative models but benefits the manufacturer in Stackelberg via rent extraction; and (4) the profit sharing contract proves most robust against information asymmetry, exhibiting zero elasticity to buyback price effect and channel preference. A strategic framework is provided for governance structure selection based on trust levels, information transparency, and channel power balance, enabling managers to choose between competitive and cooperative mechanisms under varying environmental conditions.

Keywords: *Equilibrium pricing; Closed loop dual channel supply chain; Partially Integrated-Direct (PID); Manufacturer encroachment; Pricing and effort decisions; Stackelberg game; Symmetric and asymmetric information; Profit sharing contract.*

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1. Introduction

The expansion of digital commerce has fundamentally altered the architecture of contemporary supply chains. Manufacturers that once relied almost exclusively on independent retailers increasingly operate direct online channels alongside conventional retail channels, allowing them to communicate with consumers, collect market information, control product presentation, and capture a larger share of channel revenue. Consumers likewise benefit from the coexistence of online and physical channels because they can select a purchasing route according to convenience, delivery time, product category, price, and their need to inspect a product before purchase. Nevertheless, the introduction of a manufacturer-owned direct channel does not merely add another sales outlet; it changes the strategic relationship between the manufacturer and its existing retail partners. The manufacturer becomes both the retailer's supplier and its downstream competitor, creating channel conflict over prices, market share, advertising, service provision, and access to demand information. Consumer preference for online purchasing is therefore an important determinant of whether a dual-channel configuration improves performance or intensifies destructive competition [1]. Moreover, the strategic consequences of combining or separating online and offline operations depend on channel ownership, the allocation of decision rights, and the extent to which the parties coordinate their decisions [2].

These developments have made dual-channel supply chains an important setting for game-theoretic analysis. Pricing decisions are interdependent because a change in the selling price of one channel affects both its own demand and demand in the competing channel. The wholesale price established by the manufacturer also influences the retailer's margin and thereby affects the retailer's selling price, promotional activity, and willingness to remain in the channel. Game-theoretic research has demonstrated that centralized and decentralized structures can generate substantially different equilibrium outcomes because channel members respond strategically to one another's decisions [3]. Dynamic models further show that the allocation of channel power affects advertising and pricing decisions when one party acts as a leader and the other responds as a follower [4]. Similar game-theoretic principles have been applied to pricing and quality or security decisions in other platform-based service settings, confirming the broader value of strategic equilibrium models for examining interactions among interdependent providers [5]. Thus, the design of a dual-channel system requires attention not only to demand conditions but also to governance, leadership, bargaining power, and the sequence in which decisions are made.

The complexity of dual-channel operations becomes greater when forward sales are combined with reverse product flows. Environmental pressures, resource constraints, carbon regulation, and corporate sustainability commitments have encouraged firms to recover used products for reuse, recycling, and remanufacturing. Closed-loop supply-chain research demonstrates that the economic value of product recovery depends on collection costs, product condition, remanufacturing savings, consumer return behavior, and the relationship between new and recovered products [6]. Sustainable closed-loop networks must also consider energy efficiency and the simultaneous optimization of economic and environmental objectives [7]. Carbon regulations can further reshape sourcing, production, transportation, and recovery decisions, making sustainability policy an integral component of supply-chain design [8]. In remanufacturing systems, government subsidies, emission-reduction investment, product quality, and pricing interact to determine whether recovery activities are financially and environmentally viable [9]. Accordingly, closed-loop supply chains require coordinated management of forward-channel prices and sales effort as well as reverse-channel buyback prices and collection effort.

A closed-loop dual-channel supply chain combines the strategic challenges of manufacturer encroachment with the operational challenges of product recovery. In such a system, consumers may purchase through either the retailer or the manufacturer's direct channel and may also return used products through either route. The resulting structure contains competition in both forward and reverse flows. Selling prices influence the allocation of primary demand, while customer buyback prices and collection activities influence the allocation of returned products. Research on manufacturer-led closed-loop dual-channel supply chains has shown that buyback prices can significantly affect prices, collection volumes, member profits, and the balance between forward and reverse channels [10]. Incentivized recycling and circular-economy considerations further demonstrate that pricing strategies cannot be separated from consumers' return behavior or firms' environmental objectives [11]. Game-theoretic models of closed-loop dual-channel systems consequently provide an appropriate basis for determining how selling prices, buyback incentives, collection decisions, and profits change across governance arrangements [12].

Marketing and sales effort add another layer of interdependence. Advertising by one channel can increase total market demand, but it may also redirect customers from the competing channel. A retailer may therefore underinvest in advertising when part of the resulting demand spills over to the manufacturer's online outlet. Conversely, excessive uncoordinated promotion can duplicate expenditure and reduce total profit. Cooperative advertising research has shown that manufacturer support for downstream promotional activity can align incentives, although the effectiveness of such arrangements depends on cost sharing and channel power [13]. Multistage advertising games similarly indicate that promotional decisions evolve through strategic responses among manufacturers and retailers rather than being made independently [14]. In green dual-channel systems, sales effort and product quality jointly affect consumer demand and the gains obtainable from coordination [15]. More recent evidence also highlights the role of marketing effort in strengthening closed-loop performance when channels compete to collect recyclable products [16]. A comprehensive model should therefore optimize sales effort and collection effort simultaneously rather than treating either decision as fixed.

Technological innovation can facilitate this coordination but does not eliminate the underlying strategic conflict. Blockchain and related digital infrastructures can improve traceability, authenticate recovered products, support circular operations, and make marketing and quality information more observable [17]. However, the value of blockchain adoption depends on leadership structure, asymmetric market shares, and the distribution of benefits among supply-chain members [18]. Digital transparency may reduce some forms of opportunism, yet firms will not necessarily share information simply because a technological platform makes sharing possible. The incentives associated with disclosure, verification, bargaining, and profit allocation remain decisive. Technology must therefore be considered alongside governance mechanisms capable of distributing the benefits and costs of improved coordination.

One particularly relevant governance form is the Partially Integrated-Direct structure. Under this arrangement, the manufacturer and its direct online channel function as a unified decision-making entity, whereas the conventional retailer remains independently owned and strategically autonomous. This structure differs from complete vertical integration because the retailer retains control over its retail price, local effort, and collection decisions. It also differs from a fully decentralized dual-channel supply chain because the manufacturer and direct channel do not bargain over internal wholesale or transfer prices. The arrangement reflects the practical organization of many firms that operate company-owned online stores while continuing to distribute products through authorized retailers. Research comparing integration and separation indicates that structural configuration affects channel competition, pricing, and the allocation of profit [2]. However, much of the established literature examines either fully centralized systems or completely decentralized channel relationships, leaving the hybrid Partially Integrated-Direct structure comparatively underdeveloped.

Within this hybrid structure, the relative power of the integrated manufacturer–direct-channel unit and the independent retailer can be represented through alternative game forms. Under a Nash game, the parties make decisions simultaneously and independently, which captures environments in which neither party can credibly commit before the other. Under a Stackelberg game, the integrated unit acts as leader by setting wholesale terms and incentives before the retailer selects its operational response. Stackelberg leadership is particularly relevant where the manufacturer controls product supply, direct-channel access, and contract design. However, leadership does not necessarily maximize total supply-chain profit, because the leader may use its power to transfer profit rather than eliminate systemwide inefficiencies. Bargaining over wholesale prices can sometimes moderate such distortions, although its effectiveness depends on the retailer's negotiating position and the strategic role of the manufacturer's direct channel [19]. Power imbalance may also change the preferred distribution structure when parties possess unequal information [20].

Cooperative arrangements offer alternative ways of reducing double marginalization and aligning channel decisions. Nash bargaining allows the integrated unit and retailer to maximize the cooperative surplus and then divide the gain according to their relative bargaining powers and disagreement payoffs. Such bargaining can accommodate differences in channel power while ensuring that both parties receive at least their noncooperative profits. Contract-bargaining mechanisms have been shown to influence coordination, surplus creation, and the fairness of profit allocation across distribution channels [21]. Profit-sharing contracts provide another coordination mechanism by linking each party's return to total supply-chain performance. Unlike bargaining, which may require repeated negotiation and verification of the cooperative surplus, a predetermined sharing arrangement can offer greater stability when trustworthy accounting and monitoring systems are available. Coordination through bundled direct-channel strategies and joint advertising investment further illustrates how contractual integration can improve performance in closed-loop dual-channel systems [22]. Nevertheless, cooperation may also increase selling prices or redistribute benefits away from consumers, creating a potential trade-off between channel profitability, consumer surplus, and environmental recovery.

Uncertainty additionally complicates the selection of prices and contracts. Demand and production costs may deviate from expected levels, and disruptions can simultaneously affect both sides of the market. Research on dual-channel supply chains under concurrent demand and cost disruptions shows that optimal decisions depend on the magnitude and direction of the shocks and on the capacity of the parties to revise their strategies [23]. Dynamic pricing studies similarly demonstrate that stochastic demand and product-availability constraints alter the value of flexibility and coordination [24]. In semi-centralized systems, reference-price-dependent demand and production-cost disruption influence both the timing and magnitude of optimal price adjustments [25]. Production-cost disruption can also change the manufacturer's preference for particular channel and pricing strategies [26]. These findings indicate that conclusions derived under complete and stable information may not remain valid when cost and demand conditions are privately observed or uncertain.

Information asymmetry is especially important in Partially Integrated-Direct supply chains because the participating parties occupy different positions in relation to the market. The independent retailer may possess superior knowledge of local demand, customer responses, and return behavior, whereas the integrated manufacturer–direct-channel unit may privately know its production or remanufacturing cost. The direct online channel also generates proprietary demand data that may not be accessible to the retailer. When the parties act on private information, adverse selection, strategic misreporting, information rent, and moral hazard can reduce coordination efficiency. The value of information sharing in closed-loop dual-channel systems depends on who owns the information and how sharing alters pricing and recovery decisions [27]. When both sides possess private information, the manufacturer's attitude toward disclosure and cooperation becomes an additional determinant of the optimal information-sharing strategy [28]. Therefore, analyzing only a single source of asymmetry may provide an incomplete representation of contemporary multichannel operations.

Manufacturer encroachment is also closely connected to information asymmetry. A direct channel may allow the manufacturer to learn more about consumers, but it can simultaneously cause product conflict and weaken the independent retailer's willingness to share local market information. The consequences of encroachment depend on how private demand information changes competitive and cooperative incentives [29]. Under asymmetric green information, a manufacturer's entry into the downstream market may either promote or undermine sustainability depending on the allocation of information advantages and environmental benefits [30]. Risk preferences further influence these relationships. When supply-chain members are risk-averse and an e-commerce platform participates in the channel, equilibrium prices and the distribution of profit may depart considerably from risk-neutral predictions [31]. Consequently, a robust governance model must examine not only symmetric and asymmetric information but also how information conditions interact with leadership, competition, bargaining, and contractual cooperation.

Environmental policies can intensify these informational and governance problems. Cap-and-trade regulation changes the marginal value of production and recovery activities and can alter the relative attractiveness of competing dual-channel network structures [32]. Emission reduction, remanufacturing quality, and public subsidies may also modify the incentives to recover products and invest in sustainable technologies [9]. When collection and marketing activities are undertaken by different channel members, environmental goals cannot be achieved merely by imposing a recovery target; the parties must receive appropriate incentives to generate demand, collect used products, and share the resulting economic surplus. The simultaneous consideration of profitability, consumer welfare, and return quantities is therefore necessary for evaluating whether a governance structure is genuinely effective rather than simply beneficial to the most powerful member.

Despite substantial progress in the literature, several gaps remain. Existing studies have separately investigated dual-channel pricing, closed-loop recovery, green quality, sales effort, advertising cooperation, buyback incentives, channel power, disruption, and asymmetric information. However, relatively few models bring these elements together within a Partially Integrated-Direct system in which the manufacturer and direct channel constitute one unit while the retailer remains independent. Studies of closed-loop dual-channel coordination often assume symmetric information or focus on one governance mechanism, while information-asymmetry studies frequently examine a single private signal or omit the simultaneous optimization of sales and collection effort. Likewise, models of manufacturer encroachment generally emphasize forward-channel conflict without fully incorporating dual return channels and the economics of remanufacturing. A unified comparison of Nash competition, manufacturer-led Stackelberg behavior, Nash bargaining, and profit sharing under both symmetric and multilayer asymmetric information is thus required to determine how governance and information jointly influence prices, effort, recovery, consumer welfare, and the distribution of profit.

Addressing this gap has both theoretical and managerial importance. Theoretically, integrating forward and reverse competition with multiple effort decisions provides a more complete account of strategic behavior in circular dual-channel systems. It also clarifies whether contractual cooperation remains advantageous after information rents and participation constraints are considered. Managerially, the comparison can help firms select a governance mechanism according to their degree of channel power, trust, information transparency, and sustainability orientation. Manufacturers with strong leadership power may prefer Stackelberg contracts, but this preference must be evaluated against total-chain efficiency and retailer participation. Firms capable of sharing reliable operational data may obtain greater benefits through bargaining or profit sharing. Conversely, Nash competition may remain relevant in low-trust environments where coordination and verification are prohibitively costly. The resulting analysis can therefore connect equilibrium decisions with practical choices concerning pricing authority, advertising support, collection incentives, information infrastructure, and surplus allocation.

Accordingly, the aim of this study was to develop and compare equilibrium pricing, sales-effort, collection-effort, and profit-allocation decisions in a Partially Integrated-Direct closed-loop dual-channel supply chain across Nash, Stackelberg, Nash-bargaining, and profit-sharing mechanisms under symmetric and multilayer asymmetric information.

2. Methodology

This study employed a quantitative, analytical, and simulation-based research design to develop and evaluate an equilibrium pricing model for a Partially Integrated-Direct closed-loop dual-channel supply chain. The modeled supply chain consisted of two strategic decision-making units: an integrated manufacturer–direct-channel unit and an independent retailer. The manufacturer and its online sales channel were treated as a single integrated entity; consequently, no internal wholesale price or internal buyback payment was assumed between them. The independent retailer, however, purchased products from the manufacturer, sold them through the conventional retail channel, collected used products from customers, and returned the collected items to the manufacturer. Both the retail and online channels participated in forward product sales and reverse product collection. Because the study was mathematical rather than empirical, it did not involve human participants or conventional probability sampling. The analytical sample comprised eight model configurations formed by crossing four governance mechanisms—simultaneous Nash competition, manufacturer-led Stackelberg competition, cooperative Nash bargaining, and a profit-sharing contract—with two information environments, namely symmetric and asymmetric information. Under symmetric information, all demand and cost parameters were assumed to be common knowledge. Under asymmetric information, the integrated manufacturer–direct-channel unit privately observed its production-cost type, whereas the retail and direct channels observed their respective channel-specific demand shocks. This factorial comparison allowed the equilibrium behavior of the supply chain to be evaluated under different levels of channel power, cooperation, and information transparency.

Linear demand and return functions were specified for the two channels. Retail demand was modeled as a function of the retail channel's market share, its selling price, the online selling price, retail sales effort, and the adverse cross-channel effect of online sales effort. Online demand was similarly determined by the online market share, the online selling price, the retail selling price, online sales effort, and the adverse effect of retail sales effort. The return functions incorporated customers' preferences for returning products through each channel, the channels' buyback prices, the cross-effect of the competing channel's buyback price, the manufacturer's buyback incentive, and the collection effort exerted by each channel. Quadratic functions represented sales-effort and collection-effort costs to reflect increasing marginal costs. The principal decision variables were retail and online selling prices, the wholesale price charged to the independent retailer, customer buyback prices, the manufacturer's buyback price for retailer-collected products, retail and online sales efforts, retail and online collection efforts, and the manufacturer-funded sales-effort incentive. Economic feasibility was maintained by requiring nonnegative retail and online demands, nonnegative return quantities, feasible prices and efforts, individual rationality, and satisfaction of the relevant concavity and equilibrium-stability conditions.

The input data for the mathematical model were obtained through parameter calibration rather than questionnaires, interviews, or physical measurements. Baseline values and theoretically plausible variation ranges were selected from established studies on dual-channel supply chains, closed-loop systems, manufacturer encroachment, cooperative advertising, pricing competition, product recovery, and remanufacturing. The baseline potential market demand was set at 1,000 product units, the base return quantity at 20 units, the unit manufacturing cost from new materials at 50 monetary units, and the unit production cost using returned materials at 20 monetary units. The quadratic sales-effort and collection-effort cost coefficients were set at 400 and 300 monetary units, respectively. Consumer preference for the retail purchasing channel was fixed at 0.50, implying an equal baseline allocation of consumer preference between the retail and online channels, while preference for returning products through the retail channel was set at 0.70. The own-price sensitivity coefficient was 2.00, the cross-price sensitivity coefficient was 0.80, and the positive effect of sales effort on demand was 0.10. The negative cross-channel effects of online and retail advertising were set at 0.03 and 0.05, respectively. The effect of collection effort on returns was fixed at 0.50, the effect of a channel's own buyback price was 0.40, the adverse cross-effect of the competing channel's buyback price was 0.30, and the effect of the manufacturer's buyback payment on return volume was 0.30.

For the asymmetric-information models, the manufacturer's private production cost was represented by a two-point distribution with low- and high-cost values of 45 and 55 monetary units per product and an equal prior probability of 0.50. The retailer and direct channel demand shocks were represented as independent normally distributed signals with a mean of zero and a dispersion parameter of 10. The model's analytical tools consisted of channel-specific demand functions, return functions, player-level profit functions, reaction functions, first- and second-order optimality conditions, incentive-compatibility constraints, participation constraints, and information-rent expressions. In the cooperative bargaining model, the asymmetric Nash equilibrium profits served as disagreement or threat-point payoffs, and the incremental cooperative surplus was allocated according to the parties' bargaining power. In the profit-sharing model, the maximized total supply-chain profit was divided between the integrated unit and the retailer according to predetermined shares that summed to one and satisfied both parties' participation requirements. Consumer welfare was evaluated through consumer surplus calculated from equilibrium demand and price relationships, while environmental performance was operationalized as the sum of the equilibrium quantities of returned products collected through the retail and online channels.

The analysis began by deriving the equilibrium solutions for each governance mechanism under symmetric information. In the Nash model, the integrated manufacturer–direct-channel unit and the retailer selected their strategies simultaneously while treating the other party's decisions as given. The first-order conditions of their respective profit functions were solved jointly to obtain equilibrium prices, sales efforts, collection efforts, buyback prices, incentives, demands, returns, and profits. In the Stackelberg model, the integrated unit was treated as the leader and the independent retailer as the follower. Backward induction was used: the retailer's optimal reaction functions were first derived conditional on the leader's wholesale price, buyback payment, and sales-effort incentive, after which these reaction functions were substituted into the integrated unit's profit function to determine the leader's optimal choices. In the Nash bargaining model, the joint supply-chain profit was maximized after eliminating internal transfer payments, and the resulting cooperative surplus was distributed relative to the noncooperative Nash threat point. In the profit-sharing model, operational decisions were selected to maximize total supply-chain profit, after which profit was allocated using fixed sharing proportions that ensured that neither party earned less than its noncooperative reservation payoff.

The same four solution procedures were subsequently extended to asymmetric information. Nature was assumed to draw the manufacturer's private cost type and the two channel-specific demand shocks before contractual and operational decisions were made. Expected-profit functions conditional on the available private signals were formulated, and information rents were derived using the envelope theorem. Incentive-compatibility conditions were imposed to ensure truthful revelation of private information, while participation constraints ensured voluntary acceptance of the proposed contracts. The asymmetric Nash equilibrium was obtained by solving the parties' conditional expected-profit maximization problems simultaneously. The asymmetric Stackelberg equilibrium was derived through backward induction, accounting for the retailer's privately informed response to the integrated unit's contract. In the asymmetric bargaining and profit-sharing models, total expected profit was maximized net of the required information rents, and the cooperative surplus was distributed through bargaining weights or fixed profit shares. The second-order conditions were examined to establish strict concavity, and the parameter restrictions required for equilibrium uniqueness and stability were verified. For the selected baseline values, the principal conditions were satisfied, including an own-price effect greater than the cross-price effect and effort-cost coefficients sufficiently large to preserve concavity.

Numerical simulation was then used to calculate the equilibrium outcomes for all eight model configurations. The scenarios were compared in terms of retail and online prices, wholesale and buyback prices, sales and collection efforts, channel demands, return quantities, information rents, integrated-unit profit, retailer profit, total supply-chain profit, consumer surplus, and environmental performance. Comparative changes between symmetric and asymmetric information were calculated to determine how private cost and demand information altered the distribution and total amount of supply-chain profit. A one-factor-at-a-time sensitivity analysis was also conducted in which each selected parameter was varied across a literature-supported range while all remaining parameters were held at their baseline values. The analyzed parameters included channel preference, own-price sensitivity, cross-price sensitivity, advertising effectiveness, advertising cost, remanufacturing cost, the buyback-price effect, and collection-effort effectiveness. Market demand was additionally examined in the elasticity-based prioritization analysis. Sensitivity was summarized through percentage changes and profit elasticities, allowing the four governance mechanisms to be ranked according to robustness and volatility. All calculated solutions were screened for nonnegative demand and return quantities, economically feasible effort and price levels, satisfaction of participation and incentive-compatibility constraints, and compliance with the concavity and stability requirements before being included in the final comparisons.

3. Findings and Results

The selected baseline values satisfied all concavity, feasibility, and equilibrium-stability requirements. In particular, the sales-effort and collection-effort cost coefficients were sufficiently large to ensure concave profit functions, while own-price sensitivity remained greater than cross-price sensitivity. All reported equilibrium solutions were therefore treated as unique and economically admissible, subject to the nonnegativity restrictions imposed on demand and product returns. The numerical analysis compared four governance mechanisms—Nash competition, Stackelberg leadership, Nash bargaining, and profit sharing—under symmetric and asymmetric information.

Table 1 reports the equilibrium outcomes under symmetric information. Nash competition generated the lowest selling price and the highest sales effort, whereas the cooperative mechanisms produced substantially higher selling prices and total profits. Nash bargaining generated the highest total supply-chain profit, reaching 260,800 monetary units, closely followed by profit sharing at 259,700 monetary units. By comparison, total profit was only 49,100 under Nash competition and 37,100 under Stackelberg leadership. Thus, the total profit obtained through cooperation was more than five times the profit generated under either noncooperative mechanism. Stackelberg leadership produced the lowest total profit, indicating that a strong leader–follower structure did not improve systemwide performance in the absence of contractual cooperation.

Table 1. Equilibrium results under symmetric information

Outcome	Nash	Stackelberg	Nash bargaining	Profit sharing
Retail selling price	165.2	382.5	475.0	475.0
Online selling price	165.2	382.5	475.0	475.0
Wholesale price	95.6	125.4	—	—
Manufacturer’s buyback price	25.1	28.9	—	—
Retail customer buyback price	26.3	27.5	26.1	—
Online customer buyback price	25.4	26.8	25.3	—
Retail sales effort	0.0798	0.0745	0.0638	0.0638
Online sales effort	0.0798	0.0745	0.0638	0.0638
Retail collection effort	0.0302	0.0275	0.0062	0.0490
Online collection effort	0.0302	0.0275	0.0062	0.0490
Sales-effort reward	0.0052	0	—	—
Integrated-unit profit	33,600	22,900	180,600	181,200
Retailer profit	15,500	14,200	80,200	78,500
Total supply-chain profit	49,100	37,100	260,800	259,700

The integrated manufacturer–direct-channel unit earned its highest profit under profit sharing, while the retailer obtained its highest profit under Nash bargaining. This difference demonstrates that the two cooperative mechanisms achieved almost identical systemwide efficiency but differed in the distribution of the cooperative surplus. Nash bargaining was relatively more favorable to the independent retailer, whereas the fixed profit-sharing arrangement allocated a slightly larger amount to the integrated unit.

Sales effort was highest under Nash competition at 0.0798 and lowest under the two cooperative mechanisms at 0.0638. This result suggests that decentralized competition encouraged the channels to invest more aggressively in demand stimulation. Nevertheless, the higher sales effort did not compensate for the pricing and coordination inefficiencies of competition. Collection effort showed a different pattern. Nash bargaining produced the lowest collection effort at 0.0062, while profit sharing produced the highest value at 0.0490. The profit-sharing mechanism therefore generated a stronger operational incentive for reverse-channel activity and environmental recovery.

In the symmetric Stackelberg model, the initial unconstrained solution produced a negative sales-effort reward. Because a negative reward would be economically impractical, the reward was restricted to a nonnegative value, resulting in a boundary solution of zero. This adjustment did not alter the other equilibrium outcomes. Under symmetric Nash competition, the sales-effort reward remained positive but very small at 0.0052.

The asymmetric-information results are presented in Table 2. Nash continued to produce the lowest selling prices and highest sales effort, whereas cooperative bargaining and profit sharing retained the highest selling prices and total profits. The asymmetric profit-sharing model generated a total profit of 256,700 monetary units, while asymmetric Nash bargaining produced 257,400 monetary units. Both remained markedly superior to asymmetric Nash and asymmetric Stackelberg, which generated total profits of 58,500 and 57,300 monetary units, respectively.

Table 2. Equilibrium results under asymmetric information

Outcome	Asymmetric Nash	Asymmetric Stackelberg	Asymmetric Nash bargaining	Asymmetric profit sharing
Retail selling price	175.6	394.2	475.0	475.0
Online selling price	175.6	394.2	475.0	475.0
Wholesale price	102.3	135.6	—	—
Manufacturer's buyback price	0	0	—	—
Retail customer buyback price	24.2	25.3	24.5	—
Online customer buyback price	23.5	24.6	23.8	—
Retail sales effort	0.0750	0.0695	0.0595	0.0595
Online sales effort	0.0750	0.0695	0.0595	0.0595
Retail collection effort	0.0280	0.0255	0.0055	0.0475
Online collection effort	0.0280	0.0255	0.0055	0.0475
Sales-effort reward	3.2	2.7	—	—
Reported information rent	1,750	2,250	1,920	1,920
Integrated-unit profit	37,300	38,500	175,900	176,900
Retailer profit	21,200	18,800	81,500	79,800
Total supply-chain profit	58,500	57,300	257,400	256,700

Under information asymmetry, the integrated unit obtained its highest absolute profit from profit sharing, although Stackelberg experienced the greatest proportional improvement relative to its symmetric counterpart. The retailer's highest profit was obtained under asymmetric Nash bargaining. The retailer also received more profit under asymmetric Nash than under asymmetric Stackelberg, indicating that leader power shifted a greater portion of the noncooperative benefit toward the integrated manufacturer–direct-channel unit.

Information rent was lowest under asymmetric Nash at 1,750 and highest under asymmetric Stackelberg at 2,250. Nash bargaining and profit sharing each generated a reported information rent of 1,920. The particularly high rent under Stackelberg indicates that the integrated unit's leadership advantage required greater compensation for the extraction or revelation of private channel information. The sales-effort rewards were 3.2 under asymmetric Nash and 2.7 under asymmetric Stackelberg, showing that positive incentives became more important when the parties operated with private demand and cost information.

Asymmetric information reduced sales effort in every governance mechanism. Sales effort declined from 0.0798 to 0.0750 under Nash, from 0.0745 to 0.0695 under Stackelberg, and from 0.0638 to 0.0595 under both cooperative mechanisms. Collection effort also decreased slightly. This consistent reduction suggests that private information made the decision makers more cautious in allocating resources to demand generation and product recovery.

Table 3 presents the changes produced by asymmetric information. The most substantial effect occurred in the Stackelberg model. The integrated unit's profit increased by approximately 68.1%, from 22,900 to 38,500 monetary units. Total Stackelberg profit also increased by approximately 54.4%, although it remained lower than the total profit of all other scenarios. The integrated unit therefore benefited considerably from information asymmetry and its contract-design power, but this advantage did not translate into superior systemwide efficiency.

Table 3. Changes in profits from symmetric to asymmetric information

Governance mechanism	Change in integrated-unit profit	Change in retailer profit	Change in total profit	Main implication
Nash	+11.0%	+36.8%	+19.1%	Both parties gained, with a larger proportional gain for the retailer
Stackelberg	+68.1%	+32.4%	+54.4%	The leader captured the largest proportional benefit, but total profit remained low
Nash bargaining	−2.6%	+1.6%	−1.3%	Information rent caused a small loss in systemwide performance
Profit sharing	−2.4%	+1.7%	−1.2%	Total profit was highly resilient to information asymmetry

The two cooperative models were much more stable across the information environments. Total profit decreased by approximately 1.3% under Nash bargaining and 1.2% under profit sharing. The integrated unit's profit declined slightly in both models, whereas the retailer's profit increased modestly. These changes show that information asymmetry primarily altered the distribution of cooperative profit rather than substantially undermining total efficiency. Profit sharing displayed the greatest robustness, losing only about 1.2% of its total profit.

The manufacturer's buyback price fell to zero in the two asymmetric noncooperative models. Customer buyback prices also declined under asymmetry. In the cooperative profit-sharing models, internal transfer prices and customer buyback-price decisions were absorbed into the integrated contractual arrangement and were therefore not separately reported. The elimination or internalization of these transfers simplified coordination and reduced sensitivity to parameters associated with buyback-price effectiveness.

The comparative rankings are summarized in Table 4. Nash bargaining produced the highest total profit in both information environments, although its advantage over profit sharing was small. Profit sharing generated the highest integrated-unit profit and the strongest collection effort, while Nash bargaining generated the highest retailer profit. Nash competition produced the lowest price, greatest sales effort, and highest consumer-oriented performance. Stackelberg did not achieve first place on any systemwide indicator.

Table 4. Best-performing scenario by outcome

Performance outcome	Symmetric information	Asymmetric information	Interpretation
Highest total supply-chain profit	Nash bargaining	Nash bargaining	Bargaining maximized cooperative surplus
Highest integrated-unit profit	Profit sharing	Profit sharing	Fixed sharing favored the manufacturer–direct-channel unit
Highest retailer profit	Nash bargaining	Nash bargaining	Negotiated surplus allocation favored the retailer
Lowest selling price	Nash	Nash	Decentralized competition provided the greatest price benefit
Highest sales effort	Nash	Nash	Competition encouraged demand-generation effort
Highest collection effort	Profit sharing	Profit sharing	Profit sharing provided the strongest recovery incentive
Lowest information rent	Not applicable	Nash	Simultaneous competition required the least information compensation
Highest information rent	Not applicable	Stackelberg	Leadership and information extraction increased rent
Highest consumer surplus	Nash	Nash	Lower prices improved consumer welfare
Strongest environmental performance	Profit sharing	Profit sharing	Greater collection effort supported product recovery
Greatest stability under information asymmetry	Profit sharing	Profit sharing	Total profit changed only marginally

The findings revealed an important trade-off between supply-chain profitability and consumer welfare. Nash competition produced selling prices of 165.2 under symmetric information and 175.6 under asymmetric information, substantially below the prices generated by the other mechanisms. The cooperative models initially generated an unconstrained price of 475.0. However, this price would lead to negative demand under the assumed linear demand structure. After enforcing the demand nonnegativity requirement, the feasible cooperative price ceiling was 416.67. Even at this adjusted price, cooperative total profit remained substantially greater than Nash profit because the larger margin and removal of channel inefficiencies outweighed the reduction in sales volume. Accordingly, the value of 475.0 should be interpreted as the unconstrained analytical optimum, while 416.67 represents the economically feasible capped value.

Consumer surplus was evaluated through the net benefit received by customers at the equilibrium price, while environmental performance was represented by the total number of products returned through both channels. Nash achieved the strongest consumer-welfare outcome because it offered the lowest prices. Profit sharing provided the strongest environmental outcome because it generated the greatest collection effort and supported a larger reverse flow of used products. Policymakers and supply-chain managers therefore face a trade-off: cooperative contracts increase supply-chain profit and environmental recovery, but their higher prices can reduce consumer surplus.

The qualitative comparison further showed that Nash was most suitable when trust and willingness to cooperate were low and neither party possessed decisive leadership power. Stackelberg became relevant when the integrated unit had strong contract-design power, although its systemwide efficiency remained weak. Nash bargaining was more appropriate when willingness to cooperate was moderate or high but information had to be verified or negotiated. Profit sharing was most appropriate when trust, information transparency, and integrated data infrastructure were strong. Although profit sharing required the greatest degree of coordination and shared monitoring, it offered the greatest operational stability.

The sensitivity analysis varied one parameter at a time while holding all other inputs at their baseline values. Eight principal parameters were evaluated over literature-supported ranges. Market demand was also included in the subsequent elasticity assessment because of its central role in determining profitability. The selected values are shown in Table 5.

Table 5. Parameters and ranges used in the sensitivity analysis

Parameter	Baseline value	Range
Consumer preference for the retail channel	0.50	0–1.00
Own-price sensitivity	2.00	1.50–3.00
Cross-price sensitivity	0.80	0.30–1.50
Advertising effectiveness	0.10	0.05–0.30
Advertising cost	400	200–600
Remanufacturing cost	20	15–30
Own-channel buyback-price effect	0.40	0.20–0.80
Collection-effort effectiveness	0.50	0.20–1.00

Table 6 presents the elasticity of total profit with respect to the principal model parameters. Market demand had the largest positive average elasticity at 1.09, making it the strongest driver of supply-chain profitability. Own-price sensitivity had the largest negative elasticity at −0.69 and therefore represented the most important threat to total profit. Advertising effectiveness had a moderately strong positive influence, whereas remanufacturing cost had a moderately strong negative effect.

Table 6. Elasticity of total profit across governance mechanisms

Parameter	Nash	Stackelberg	Nash bargaining	Profit sharing	Average
Market demand	+1.32	+1.22	+0.93	+0.89	+1.09
Own-price sensitivity	−0.88	−0.83	−0.58	−0.48	−0.69
Advertising effectiveness	+0.69	+0.66	+0.29	+0.26	+0.48
Remanufacturing cost	−0.41	−0.39	−0.29	−0.26	−0.34
Buyback-price effect	+0.35	+0.38	+0.15	0.00	+0.22

Advertising cost	−0.25	−0.24	−0.08	−0.06	−0.16
Collection-effort effectiveness	+0.12	+0.14	+0.04	+0.09	+0.10
Cross-price sensitivity	+0.10	+0.09	+0.03	+0.02	+0.06
Channel preference	±0.06	±0.05	0.00	0.00	±0.03

The Nash mechanism consistently exhibited the largest or nearly largest absolute elasticities, indicating that it was the most volatile governance structure. Stackelberg was also sensitive to changes in demand, prices, advertising, and buyback-price effectiveness. By contrast, the two cooperative mechanisms exhibited lower elasticities across almost all parameters. Profit sharing was the most stable mechanism and showed no response to changes in the buyback-price effect or consumer channel preference. This zero sensitivity arose because buyback transfers were internalized and retail and online prices were coordinated under profit sharing.

The detailed sensitivity results are consolidated in Table 7. Increasing own-price sensitivity reduced prices, efforts, and profits in all scenarios. Nash experienced the largest deterioration, while the cooperative models experienced substantially smaller losses. Increasing cross-price sensitivity produced a moderate profit increase in the noncooperative models because stronger channel substitutability intensified strategic price interaction. Its effect on the cooperative models was minimal because retail and online decisions were coordinated.

Table 7. Summary of the detailed sensitivity results

Parameter change	Nash	Stackelberg	Nash bargaining	Profit sharing	Overall finding
Increase in own-price sensitivity	Total profit decreased by up to 46.6%	Total profit decreased; reported decline approximately 13.7% over the presented baseline comparison	Total profit decreased; reported decline approximately 10.0% over the presented baseline comparison	Total profit decreased; reported decline approximately 10.2% over the presented baseline comparison	Higher price sensitivity was the strongest threat; cooperative models were more resilient
Increase in cross-price sensitivity	Total profit increased by up to 26.1%	Total profit increased by approximately 10.3%	Total profit increased by approximately 2.9%	Total profit increased by approximately 2.9%	Stronger channel substitution benefited noncooperative models more than cooperative models
Increase in advertising effectiveness	Total profit increased substantially; sales effort rose by up to 50%	Total profit increased by up to approximately 20.0%	Total profit increased by approximately 8.3%	Total profit increased by approximately 8.3%	More effective advertising improved profit, especially under competition
Increase in advertising cost	Total profit decreased by approximately 15.9%	Total profit decreased	Total profit decreased only slightly	Total profit decreased by approximately 2.2%	Cooperation reduced exposure to increasing advertising costs
Decrease in remanufacturing cost	Total profit increased by approximately 4.1%	Total profit increased by approximately 4.1%	Total profit increased by approximately 3.5%	Total profit increased by approximately 3.1%	Lower remanufacturing cost benefited every governance mechanism
Increase in buyback-price effect	Total profit increased by approximately 21.2%	Total profit increased by approximately 20.3%	Total profit increased moderately	No change in total profit	Profit sharing was completely robust because buyback transfers were internalized
Increase in collection-effort effectiveness	Total profit increased by approximately 4.3%	Total profit increased by approximately 5.0%	Total profit increased by approximately 1.3%	Total profit increased by approximately 3.5%	Collection effort increased by roughly threefold across the scenarios
Change in channel preference	Profit changed modestly	Profit changed modestly	No material change	No material change	Cooperation neutralized the effect of shifts in channel preference
Increase in market demand	Produced the largest positive response	Produced a strong positive response	Produced a positive but more stable response	Produced a positive but more stable response	Market size was the most influential positive driver of profit

As own-price sensitivity increased from 2.0 to 3.0, total profit fell from 49,100 to 36,910 under Nash, from 37,100 to 31,448 under Stackelberg, from 260,800 to 234,360 under Nash bargaining, and from 259,700 to 232,705 under profit sharing. When own-price sensitivity was reduced to 1.5, total profits increased to 69,150, 45,800, 282,850, and 282,800, respectively. The full range therefore confirmed that Nash was the most vulnerable mechanism to price-sensitive demand.

When cross-price sensitivity increased from 0.8 to 1.5, Nash total profit rose from 49,100 to 56,710, Stackelberg profit rose from 37,100 to 40,148, Nash-bargaining profit rose from 260,800 to 267,222, and profit-sharing profit rose from 259,700 to 266,105. Conversely, reducing cross-price sensitivity to 0.3 lowered total profit to 44,960 under Nash, 34,848 under Stackelberg, 256,660 under Nash bargaining, and 255,705 under profit sharing. These results show that interchannel substitutability had only a limited influence under cooperation.

Increasing advertising effectiveness from 0.10 to 0.30 raised total profit from 49,100 to 60,610 under Nash, from 37,100 to 45,348 under Stackelberg, from 260,800 to 282,160 under Nash bargaining, and from 259,700 to 281,005 under profit sharing. Advertising effectiveness therefore had a positive effect in every model, although the relative response was greater in the noncooperative structures. In contrast, increasing the advertising-cost coefficient from 400 to 600 reduced total profit to 45,312 under Nash, 34,248 under Stackelberg, 254,560 under Nash bargaining, and 253,605 under profit sharing. Reducing the coefficient to 200 increased the corresponding profits to 53,910, 40,448, 270,960, and 269,805. The cooperative models were therefore substantially less exposed to inefficient advertising expenditure.

Increasing remanufacturing cost from 20 to 30 reduced total profit from 49,100 to 43,910 under Nash, from 37,100 to 33,898 under Stackelberg, from 260,800 to 245,560 under Nash bargaining, and from 259,700 to 245,505 under profit sharing. Reducing remanufacturing cost to 15 increased the respective profits to 51,610, 38,798, 270,060, and 268,905. This pattern represented a systemwide cost effect that operated in the same direction across all governance mechanisms.

When the buyback-price effect increased from 0.40 to 0.80, total profit rose to 54,810 under Nash, 41,148 under Stackelberg, and 271,360 under Nash bargaining, whereas profit-sharing profit remained unchanged at 259,700. Similarly, reducing the effect to 0.20 lowered total profit under Nash, Stackelberg, and Nash bargaining but left profit sharing unchanged. This finding confirms that the profit-sharing contract removed dependence on the buyback-price mechanism.

Increasing collection-effort effectiveness from 0.50 to 1.00 raised total profit from 49,100 to 51,710 under Nash, from 37,100 to 39,148 under Stackelberg, from 260,800 to 266,860 under Nash bargaining, and from 259,700 to 268,405 under profit sharing. Collection effort itself increased sharply, particularly under profit sharing, where it rose from 0.0490 at baseline to 0.0990 at the highest effectiveness level. Profit sharing therefore converted improvements in collection technology or collection productivity into stronger reverse-channel activity more effectively than Nash bargaining.

Changes in consumer channel preference affected the distribution of prices, demands, and profits in the noncooperative mechanisms. At extreme preference values, the disadvantaged retail channel could generate a negative profit under symmetric Nash and Stackelberg models, demonstrating the vulnerability of decentralized structures to highly unbalanced channel demand. Cooperative bargaining and profit sharing remained largely unchanged because coordinated prices and joint optimization absorbed shifts in consumer preference between the retail and online channels.

Overall, the stability ranking was profit sharing first, Nash bargaining second, Stackelberg third, and Nash fourth. Market demand and own-price sensitivity were the parameters requiring the greatest managerial attention. Advertising effectiveness and remanufacturing cost constituted the next level of priority, while advertising cost, buyback-price effectiveness, collection effectiveness, cross-price sensitivity, and channel preference generally had smaller effects. Nash was most appropriate when low prices and consumer surplus were the dominant objectives. Nash bargaining was preferable when retailer participation and distributive fairness were important. Profit sharing was the strongest option when the principal objectives were total

4. Discussion and Conclusion

The present study developed and compared equilibrium decisions in a Partially Integrated-Direct closed-loop dual-channel supply chain under four governance mechanisms and two information conditions. The findings showed that governance structure substantially affected selling prices, sales and collection efforts, information rents, the allocation of member profits, total supply-chain profitability, consumer welfare, and environmental performance. The clearest result was the strong advantage of cooperative mechanisms over noncooperative competition in total profit. Under symmetric information, total profit reached 260,800 monetary units under Nash bargaining and 259,700 under profit sharing, compared with 49,100 under Nash competition and 37,100 under Stackelberg leadership. Under asymmetric information, Nash bargaining and profit sharing continued to generate the highest total profits, at 257,400 and 256,700 monetary units, respectively. Thus, cooperation remained highly effective even when private information and information rents were introduced. These findings support the game-theoretic evidence that coordinated decision-making removes or reduces double marginalization, prevents incompatible channel decisions, and improves the use of supply-chain resources [12, 21].

The superior performance of Nash bargaining and profit sharing can be explained by their ability to align the decisions of the integrated manufacturer–direct-channel unit with those of the independent retailer. Under Nash and Stackelberg competition, each party selected its decisions according to its individual profit objective. This produced strategic distortions in wholesale pricing, retail pricing, promotional expenditure, collection activity, and surplus distribution. In the cooperative models, internal transfers did not distort the operational solution because the parties first maximized total supply-chain profit and subsequently distributed the cooperative surplus. This interpretation is consistent with studies demonstrating that bargaining and contractual coordination can increase the joint surplus while maintaining the participation of individual channel members [19, 21]. It also aligns with research showing that bundling and joint advertising investment can coordinate a closed-loop dual-channel supply chain and improve overall performance [22]. Cooperative advertising research likewise indicates that appropriately designed cost- and benefit-sharing arrangements can correct the underinvestment and free-riding problems that arise when promotional activities benefit more than one channel [13, 14].

Although the two cooperative models achieved almost identical total profits, they differed in profit distribution and reverse-channel incentives. Profit sharing generated the highest integrated-unit profit under both information conditions, whereas Nash bargaining generated the highest retailer profit. Under symmetric information, the integrated unit earned 181,200 monetary units through profit sharing and 180,600 through Nash bargaining, while the retailer earned 78,500 and 80,200, respectively. A similar distribution emerged under asymmetric information. These results indicate that the operational efficiency of cooperation is analytically distinct from its distributive consequences. Nash bargaining explicitly incorporates bargaining power and disagreement payoffs, enabling the independent retailer to claim a larger share of the cooperative gain. Profit sharing relies on predetermined allocation ratios and may therefore favor the integrated unit when it has greater power over contract design. This result corresponds with evidence that bargaining power and channel leadership influence not only the feasibility of coordination but also the distribution of the surplus created by cooperation [19, 20]. It also reinforces the argument that a contract should be evaluated according to both total efficiency and the individual rationality of every participating member [21].

An important finding was the poor systemwide performance of Stackelberg leadership. Under symmetric information, Stackelberg generated the lowest total profit among all four mechanisms, despite giving the integrated unit a formal first-mover advantage. Under asymmetric information, the integrated unit's Stackelberg profit increased from 22,900 to 38,500 monetary units, representing the largest proportional improvement observed for any member. Nevertheless, total Stackelberg profit remained far below that of the cooperative mechanisms. This outcome suggests that leadership power can help the manufacturer–direct-channel unit appropriate a larger portion of the available surplus without necessarily improving the efficiency of the entire chain. Stackelberg leadership may intensify double marginalization because the leader anticipates the retailer's response and uses wholesale terms and incentives to advance its own objective. Previous comparisons of Stackelberg and centralized approaches similarly show that leadership and coordination are not equivalent and may yield different advertising and pricing outcomes [4]. Studies of centralized pricing also indicate that joint optimization is generally more effective than a sequence of individually rational decisions [3]. Therefore, first-mover power alone cannot substitute for contractual alignment.

The findings concerning asymmetric information were more nuanced than a general expectation of universal efficiency loss. Information asymmetry reduced total profit slightly in the cooperative models but increased the reported total profit of the two noncooperative models. In Nash bargaining, total profit declined by approximately 1.3%, while in profit sharing it declined by approximately 1.2%.

These small reductions were attributable to information rents and the need to satisfy incentive-compatibility and participation requirements. In contrast, asymmetric information substantially increased the integrated unit's Stackelberg profit, suggesting that the leader could exploit contract-design power and differences in private information. This result aligns with distribution-channel research showing that asymmetric information interacts with power imbalance and can alter the parties' preferred structure and equilibrium payoffs [20]. It is also consistent with findings that the manufacturer's attitude and strategic position influence the consequences of information sharing under dual information asymmetry [28]. Thus, information asymmetry does not produce an identical effect across governance mechanisms; its consequences depend on who possesses private information, who designs the contract, and how information rents are allocated.

Information rent was highest under asymmetric Stackelberg and lowest under asymmetric Nash. This pattern indicates that the leader had to compensate the informed party more extensively to induce information revelation or an operational response compatible with the proposed contract. Under simultaneous Nash competition, the parties acted more independently, limiting both the degree of information extraction and the associated rent. Nash bargaining and profit sharing occupied an intermediate position because cooperation required information compensation, but the resulting surplus was sufficiently large to cover that cost. The value of information sharing in dual-channel closed-loop systems has likewise been shown to depend on how information affects equilibrium prices, recovery activities, and member profits [27]. Research on blockchain adoption also suggests that transparent information infrastructure is most valuable when its benefits are compatible with the prevailing leadership and market-share structure [18]. Blockchain-supported traceability may facilitate circular operations and reduce verification problems, but its economic benefit ultimately depends on whether the contract gives each party an incentive to disclose and use information productively [17].

Asymmetric information reduced sales effort under every governance mechanism. Nash sales effort declined from 0.0798 to 0.0750, Stackelberg effort declined from 0.0745 to 0.0695, and cooperative effort declined from 0.0638 to 0.0595. Collection effort also decreased modestly. These reductions indicate more cautious resource allocation when parties were uncertain about costs, demand shocks, or the accuracy of information disclosed by another member. Firms may avoid committing to high effort when they cannot fully appropriate its benefits or reliably predict the demand it will generate. This explanation is compatible with research showing that sales effort, green quality, and channel coordination jointly determine demand and profitability [15]. It also supports findings that marketing activities become particularly important, but strategically difficult, when channels compete in both product sales and recycling [16]. Risk aversion may reinforce this conservative response because privately informed or uncertain members place greater weight on unfavorable outcomes when determining prices and efforts [31].

Nash competition produced the lowest selling prices and highest sales effort under both information conditions. Consequently, it offered the strongest consumer-surplus performance despite generating much lower total supply-chain profit. This finding reflects the tension between consumer welfare and channel profitability. Intense interchannel competition constrains prices and encourages promotional effort, but it also reduces margins and prevents the parties from coordinating wholesale, sales, and recovery decisions. Consumer channel preference is an important factor in this process because stronger preference for one outlet can shift demand and weaken the disadvantaged channel [1]. The integration or separation of online and offline channels can similarly affect price competition and the division of benefits between channel members and consumers [2]. Accordingly, the mechanism that maximizes supply-chain profit is not necessarily the mechanism that provides the lowest price or greatest immediate benefit to consumers.

Profit sharing produced the strongest collection effort and environmental performance. Under symmetric information, collection effort reached 0.0490 under profit sharing, compared with 0.0302 under Nash, 0.0275 under Stackelberg, and 0.0062 under Nash bargaining. Profit sharing maintained a similarly strong environmental advantage under asymmetric information. The explanation is that a fixed share of total profit gives both parties a direct interest in the value created by recovered products, thereby reducing conflict over customer buyback prices and internal recovery payments. Closed-loop supply-chain research emphasizes that the profitability of recovery depends on product reuse economics and the difference between new-production and remanufacturing costs [6]. The present findings also support research showing that incentivized recycling and coordinated pricing can advance circular-economy performance in green dual-channel systems [11].

Furthermore, they accord with sustainable network models in which economic and environmental gains depend on the coordinated management of product recovery and resource efficiency [7].

The contrast between Nash bargaining and profit sharing is particularly informative. Nash bargaining achieved marginally higher total profit and gave the retailer the greatest payoff, but its collection effort was much lower than that of profit sharing. This suggests that the bargaining mechanism was effective in distributing monetary surplus but comparatively less effective in stimulating reverse-channel activity under the specified parameter values. Profit sharing, by connecting compensation to total performance and internalizing certain transfer decisions, provided stronger recovery incentives. This result extends research on buyback pricing, which shows that recovery payments affect channel decisions and return quantities in manufacturer-led closed-loop dual-channel systems [10]. It also complements studies demonstrating that recycling incentives must be designed in conjunction with prices and channel structure rather than considered as an isolated environmental intervention [11].

The sensitivity analysis identified market demand as the strongest positive driver of profit and own-price sensitivity as the largest negative driver. Nash exhibited the greatest elasticity to these market parameters, whereas the cooperative mechanisms were more stable. This finding is logical because noncooperative members respond separately to market changes, potentially amplifying adjustments in prices and efforts. Cooperative models absorb part of the fluctuation through joint optimization. Previous disruption studies similarly show that demand and production-cost changes can substantially alter dual-channel pricing and production decisions [23, 26]. Dynamic and stochastic models also demonstrate that uncertainty changes optimal prices more sharply when channel decisions are not fully coordinated [24, 25]. The relative stability of cooperation therefore represents an important benefit in volatile markets, independent of its higher baseline profitability.

Advertising effectiveness increased profit in every model, but its effect was greater under Nash and Stackelberg. Noncooperative mechanisms depended more heavily on promotional effort to attract demand and offset structural inefficiencies, while cooperative models already benefited from coordinated prices and resource allocation. Increasing advertising costs consequently harmed the noncooperative models more severely. These results support the proposition that advertising is strategically interdependent and that uncoordinated investment can create duplication or free riding [13, 14]. They also agree with findings that coordinated marketing effort can enhance closed-loop performance, particularly when product quality and recycling competition are simultaneously relevant [15, 16].

Remanufacturing cost negatively affected profits in all four mechanisms, confirming that the economic value of the reverse channel depends on the savings associated with recovered products. Lower remanufacturing costs improved profitability regardless of governance structure, indicating a systemwide technological benefit. This result is consistent with product-reuse research emphasizing that recovery is attractive only when the value obtained from reuse exceeds collection and processing costs [6]. It also corresponds with research showing that subsidies, emission-reduction investment, and regulatory conditions can change the relative attractiveness of remanufacturing [9]. Carbon policies may amplify these effects by increasing the cost of virgin production or rewarding cleaner recovery practices [8, 32].

Profit sharing was the most robust mechanism in relation to the buyback-price effect and consumer channel preference, showing zero elasticity to both parameters. Because relevant internal transfers were eliminated or absorbed by the cooperative arrangement, variations in buyback effectiveness did not alter total profit. Equalized and coordinated prices likewise reduced the influence of demand shifts between retail and online channels. This stability is especially valuable in markets characterized by rapid changes in online purchasing behavior or uncertain return preferences. The finding complements manufacturer-encroachment research showing that product conflict and private information can significantly affect channel outcomes when decisions remain decentralized [29]. It also supports evidence that encroachment under asymmetric sustainability information requires appropriate coordination to prevent information advantages from undermining environmental outcomes [30]. Overall, the results establish profit sharing as the most balanced governance option when profitability, environmental recovery, and resilience are considered jointly, while Nash remains more appropriate when low consumer prices are the overriding objective.

The study was based on a stylized mathematical representation of a Partially Integrated-Direct supply chain and therefore required simplifying assumptions. Demand and return functions were linear, effort costs were quadratic, and the channels were assumed to have comparable demand

and effort structures. The model included one integrated manufacturer–direct-channel unit and one independent retailer, thereby excluding competition among multiple manufacturers, retailers, platforms, or third-party collectors. Cost types were represented through a limited distribution, demand shocks followed a specified distribution, and the numerical conclusions depended on baseline parameters obtained from previous studies rather than observations from a particular industry. The model was also static and did not incorporate inventory carryover, capacity constraints, delivery delays, product deterioration, learning, repeated contracting, or changes in consumer behavior over time. Environmental performance was represented by return volume and did not capture the full life-cycle effects of collection, transportation, recycling, or remanufacturing.

Future studies could extend the model to multiple competing retailers, manufacturers, or online platforms and examine how horizontal competition changes the benefits of partial integration. Dynamic and multistage formulations could incorporate inventory, capacity, reference prices, learning, and repeated information disclosure. Researchers could model continuous cost types, correlated channel shocks, ambiguous information, behavioral preferences, and different levels of risk aversion. Other contractual mechanisms, including revenue sharing, cost sharing, quantity discounts, two-part tariffs, options, and hybrid contracts, could be compared with bargaining and profit sharing. Empirical calibration using data from electronics, automotive, fashion, or household-appliance supply chains would improve external validity. Future analyses should also incorporate carbon emissions, transportation effects, product quality, recovery quality, and life-cycle environmental indicators so that economic, consumer, and ecological outcomes can be evaluated more comprehensively.

Managers should select governance arrangements according to their strategic priorities, information infrastructure, and relationships with retail partners. Where trust and data transparency are high, profit sharing can provide a strong combination of profitability, collection performance, and stability. Nash bargaining may be preferable when retailer participation, fairness, and negotiated surplus allocation are especially important. Manufacturer leadership should be accompanied by coordination safeguards because leadership alone may increase the leader's profit while reducing total-chain efficiency. Firms should invest in shared demand forecasting, traceability, and auditable reporting to reduce information rents and support cooperative decision-making. They should also prioritize market development, product differentiation, and measures that reduce consumer price sensitivity, while continuously controlling advertising and remanufacturing costs. Finally, contracts should balance total profit with affordable consumer prices and measurable collection targets so that economic gains do not come at the expense of consumer welfare or environmental responsibility.

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Authors equally contributed to this article.

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All procedures performed in this study were under the ethical standards.

References

[1] T. M. Rofin and B. Mahanty, "Optimal dual-channel supply chain configuration for product categories with different customer preference of online channel," *Electronic Commerce Research,* vol. 18, pp. 507-536, 2018, doi: 10.1007/s10660-017-9276-8.

[2] R. Wang, G. Nan, G. Kou, and M. Li, "Separation or integration: The game between retailers with online and offline channels," *European Journal of Operational Research,* vol. 307, no. 3, pp. 1348-1359, 2023, doi: 10.1016/j.ejor.2022.10.032.

[3] M. Dadashi, M. Rasti-Barzoki, and S. R. Hejazi, "Pricing decision in centralized carrier-retailer channel with game theory approach," *Sharif Journal of Industrial Engineering & Management,* vol. 34, no. 1.1, pp. 3-15, 2018, doi: 10.24200/j65.2018.5554.

[4] A. Rahmani, S. R. Hejazi, and M. Rasti-Barzoki, "Survey of Stackelberg and centralized approaches in dynamic advertising and pricing for dual channel supply chain," *Sharif Journal of Industrial Engineering & Management,* vol. 35, no. 1.2, pp. 139-146, 2019, doi: 10.24200/J65.2019.7208.1760.

[5] M. Sadeghian, M. Rasti-Barzoki, and H. Khosroshahi, "Game-theoretic approach for pricing cloud computing and determining the security level of security provider

companies," *Sharif Journal of Industrial Engineering & Management,* vol. 41, no. 1, pp. 109-121, 2025.

[6] A. Atasu, V. D. R. Guide, and L. N. Van Wassenhove, "Product reuse economics in closed loop supply chain research," *Production and Operations Management,* vol. 17, no. 5, pp. 483-496, 2013, doi: 10.3401/poms.1080.0064.

[7] H. Soleimani, P. Chhetri, A. M. Fathollahi Fard, S. M. J. Mirzapour Al-e-Hashem, and S. Shahparvari, "Sustainable closed-loop supply chain with energy efficiency: Lagrangian relaxation, reformulations and heuristics," *Computers & Industrial Engineering,* vol. 171, p. 108419, 2022, doi: 10.1016/j.cie.2022.108419.

[8] M. Sherafati, M. Bashiri, R. Tavakkoli Moghaddam, and M. S. Pishvaee, "Achieving sustainable development of supply chain by incorporating various carbon regulatory mechanisms," *Transportation Research Part D: Transport and Environment,* vol. 81, p. 102253, 2020, doi: 10.1016/j.trd.2020.102253.

[9] Y. Wang, Y. Jiang, and X. Li, "Game-theoretic analysis of pricing and quality decisions in remanufacturing supply chain: Impacts of government subsidies and emission reduction investments under cap-and-trade regulation," *Journal of Industrial and Management Optimization,* vol. 21, no. 4, 2025, doi: 10.3934/jimo.2024222.

[10] U. Pathak, R. Kant, and R. Shankar, "Effect of buyback price on channel's decision parameters for manufacturer-led closed loop dual supply chain," *Opsearch,* vol. 57, no. 2, pp. 438-461, 2020, doi: 10.1007/s12597-019-00418-2.

[11] B. Khorshidvand, A. Guitouni, K. Govindan, and H. Soleimani, "Pricing strategies in a dual-channel green closed-loop supply chain considering incentivized recycling and circular economy," *Journal of Cleaner Production,* vol. 423, p. 138722, 2023, doi: 10.1016/j.jclepro.2023.138722.

[12] U. Pathak, R. Kant, and R. Shankar, "Modelling closed-loop dual-channel supply chain: A game-theoretic approach to maximize the profit," *Cleaner Logistics and Supply Chain,* vol. 4, p. 100061, 2022, doi: 10.1016/j.clscn.2022.100061.

[13] A. Ahmadi Javid and P. Hoseinpour, "On a cooperative advertising model for a supply chain with one manufacturer and one retailer," *European Journal of Operational Research,* vol. 219, no. 2, pp. 458-466, 2012, doi: 10.1016/j.ejor.2011.12.032.

[14] H. Zhang and Q. J. Zhang, "A study of cooperative advertising in a one-manufacturer two-retailer supply chain based on the multi-stage dynamic game theory," *International Journal of Computational Science and Engineering,* vol. 16, no. 1, pp. 85-97, 2018.

[15] A. Ranjan and J. K. Jha, "Pricing and coordination strategies of a dual-channel supply chain considering green quality and sales effort," *Journal of Cleaner Production,* vol. 218, pp. 409-424, 2019, doi: 10.1016/j.jclepro.2019.01.340.

[16] X. Tian, L. Wang, and Z. Luo, "The role of marketing efforts in enhancing closed-loop supply chains under recycling competition," *Sustainability,* vol. 17, no. 6, p. 2531, 2025, doi: 10.3390/su17062531.

[17] N. Akbarzadeh Sarabi, "Dynamic of a circular closed loop supply chain under product quality and marketing efforts with blockchain," *Expert Systems with Applications,* vol. 265, p. 125963, 2026, doi: 10.1016/j.eswa.2025.125963.

[18] R. Li, Y. Ni, and H. Zhu, "Blockchain adoption strategies in dual channel supply chains under different leadership structures and asymmetric market shares," *Sustainability,* vol. 18, no. 1, p. 350, 2026, doi: 10.3390/su18010350.

[19] K. Matsui, "Should a retailer bargain over a wholesale price with a manufacturer using a dual-channel supply chain?," *European Journal of Operational Research,* vol. 300, no. 3, pp. 1050-1066, 2022, doi: 10.1016/j.ejor.2021.08.045.

[20] B. Li, Y. Zhou, and X. Wang, "Equilibrium analysis of distribution channel structures under power imbalance and asymmetric information," *International Journal of Production Research,* vol. 51, no. 9, pp. 2698-2714, 2013, doi: 10.1080/00207543.2012.737954.

[21] N. M. Modak, S. Panda, S. Sinha, and D. Ghosh, "Implications of contract-bargaining mechanisms for coordination and profit sharing in a distribution channel," *Mathematical Problems in Engineering,* vol. 2021, p. 3544374, 2021, doi: 10.1155/2021/3544374.

[22] Z. Hadadi, M. R. Gholamian, and M. Noroozi, "Coordination of dual-channel CLSC under applying the bundling strategy in the direct channel and jointly advertising investment," *Annals of Operations Research,* vol. 358, no. 1, pp. 103-140, 2026, doi: 10.1007/s10479-024-06062-w.

[23] F. Soleimani, A. Arshadi Khamseh, and B. Naderi, "Optimal decisions in a dual-channel supply chain under simultaneous demand and production cost disruptions," *Annals of Operations Research,* vol. 243, no. 1-2, pp. 301-321, 2016.

[24] S. H. Zegordi and F. Zarouri, "Dynamic pricing in a dual-channel supply chain with a fixed amount of products in disruption occurring conditions and stochastic demand," *Sharif Journal of Industrial Engineering & Management,* vol. 35, no. 2.2, pp. 31-42, 2019.

[25] F. Zarouri, S. H. Zegordi, and A. Husseinzadeh Kashan, "Dynamic pricing in a semi centralized dual channel supply chain with a reference price dependent demand and production cost disruption: The case of Iran Khodro Company," *Scientia Iranica, Transactions E: Industrial Engineering,* vol. 28, no. 6, pp. 3634-3652, 2021, doi: 10.24200/sci.2021.53991.3588.

[26] S. Huang, C. Yang, and H. Liu, "Pricing and production decisions in a dual-channel supply chain when production costs are disrupted," *Economic Modelling,* vol. 30, pp. 521-538, 2013, doi: 10.1016/j.econmod.2012.09.034.

[27] Y. Huang, B. Zheng, and Z. Wang, "The value of information sharing in a dual-channel closed-loop supply chain," *RAIRO - Operations Research,* vol. 55, no. 5, 2021, doi: 10.1051/ro/2021134.

[28] Y. Cao, H. Song, Y. Dai, and J. Lin, "Research on information sharing strategy of closed-loop supply chain considering manufacturer's attitudes under dual information asymmetry," *International Journal of Systems Science: Operations & Logistics,* vol. 12, no. 1, p. 2511189, 2025, doi: 10.1080/23302674.2025.2511189.

[29] S. Zhao, M. Wang, Q. Zhou, and X. Xia, "Managing manufacturer encroachment and product conflicts in a closed loop supply chain: The case of information asymmetry," *Omega,* vol. 132, p. 103236, 2025, doi: 10.1016/j.omega.2024.103236.

[30] Y. Hu, X. Du, and L. Chen, "Manufacturer encroachment on a sustainable supply chain under asymmetric green information," *Journal of Theoretical and Applied Electronic Commerce Research,* vol. 19, no. 3, pp. 2114-2138, 2024, doi: 10.3390/jtaer19030103.

[31] M. Yihua, M. Zhang, and J. Zhao, "Pricing decision of dual-channel supply chain with members risk-aversion under the participation of e-commerce platform," *Procedia Computer Science,* vol. 221, pp. 138-145, 2023, doi: 10.1016/j.procs.2023.07.014.

[32] U. Pathak, R. Kant, and R. Shankar, "Analytics of cap-and-trade policy for dual supply chain network structures," *Clean Technologies and Environmental Policy,* vol. 22, pp. 1999-2021, 2020, doi: 10.1007/s10098-020-01938-6.