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TWO-STAGE SUPPLY CHAIN PRICING STRATEGIES WITH REFERENCE PRICE EFFECT

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Abstract. Products sold to the market typically traverse the introductory and maturity stages. During maturity, retailers often raise prices to capitalize on expanding market demand. However, consumers commonly regard the first-stage price as a psychologically acceptable reference point. When the second-stage price exceeds this threshold, they tend to perceive it as unfair, leading to a decrease in demand. Conversely, a price decrease strategy can leverage the reference price effect to stimulate purchases. This study investigates optimal two-stage supply chain pricing under dynamic market expansion with the reference price effect. We develop a Stackelberg game model involving a manufacturer and a retailer, analyzing both centralized and decentralized decision-making to explore how the reference price effect affects pricing, profit allocation, and supply chain coordination. The main findings are as follows: (1) Under centralized decision-making, moderate market expansion prompts second-stage price decreases to mitigate reference price effect's negative impacts and stimulate demand; substantial expansion enables a price increase strategy to exploit reference price effect for higher unit profitability; (2) Decentralized decision-making with reference price effect exacerbates double marginalization. Moreover, manufacturers' first-stage wholesale prices are independent of reference price effect, while second-stage wholesale prices decrease as it strengthens; (3) To achieve supply chain coordination, a two-part tariff contract with fixed fees across two stages is proposed, effectively aligning incentives and enhancing profits across varying market expansion scenarios. Numerical analyses further identify parameter regions for optimal price strategies, quantify the reference price effect's profit-impact thresholds, and sensitivity analysis of key parameters.

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1. Introduction

The life cycle of a product in the market can be divided into two stages: introduction and maturity. During the introduction stage, a new product is launched into the market, where consumer awareness is limited, resulting in a smaller initial market size. As advertising, marketing efforts, and positive word-of-mouth accumulate, the product gradually transitions into the maturity phase, during which there is a significant expansion of the

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market. In response to this change, companies often contemplate increasing the product price during maturity to enhance profitability. However, as consumers become more sensitive to reference prices, a price increase in the maturity phase may be perceived as exceeding the consumers' threshold of price fairness, triggering negative perceptions of transaction fairness and reducing market demand.

Extensive research in behavioral economics has established that consumers' perception of price fairness considerably affects their purchase decisions [53]. When consumers purchase products, they have an acceptable reference price in mind, which is the fair price they consider reasonable. When a company's pricing exceeds this reference price, consumers may feel that the transaction is unfair, resulting in a negative psychological effect, leading them to refuse the transaction or even to boycott the brand to protest its high pricing strategy [38]. For instance, when Netflix – a well-known American streaming media platform – unexpectedly announced a price increase in 2014, this adjustment deviated significantly from consumers' reference prices. Consequently, it led to a decreased willingness among customers to purchase subscriptions and compelled them to reconsider their commitments to other streaming services under budget constraints [21].

Companies remain incentivized to raise prices in response to a market characterized by increasing demand during the maturity phase, despite the potential for such price increases to generate dissatisfaction among price-sensitive consumers and subsequently reduce demand [13, 20, 44]. This strategy is predicated on the premise that higher prices can yield greater profits per unit sold, thereby enhancing overall profitability. The successful implementation of this approach necessitates a comprehensive understanding of prevailing market conditions and consumer behavior, alongside an ongoing commitment to profit maximization. However, it is important to note that the reference price effect does not invariably lead to decreased demand. When companies employ discount strategies, they can elicit positive psychological responses from consumers. For instance, Galanz – often referred to as the "price cutter" – has effectively utilized discount strategies to expand its market share annually. Presently, Galanz stands as the world's largest manufacturer of microwave ovens with a commanding market share of approximately 35%. During significant annual events such as "Double 11" and other festive periods in China, numerous companies also implement ultra-low pricing strategies aimed at stimulating substantial consumer demand; this has resulted in consistent year-on-year sales growth [29]. Furthermore, one primary reason for increased demand stemming from these pricing reduction strategies lies in consumers' tendency to regard initial high prices as their psychological reference points (perceived as fair prices). Consequently, this strategy proves effective in stimulating consumer demand during subsequent stages.

However, existing research primarily focuses on the strategic interactions between firms and consumers, as well as dynamic pricing strategies, with limited attention given to how reference price effects (RPE) influence decision-making among supply chain members under varying market scale conditions. To address this gap, this study examines a two-tier supply chain consisting of a manufacturer and a retailer, developing a two-stage dynamic game model that incorporates RPE. By employing backward induction, we derive the equilibrium outcomes under both centralized and decentralized decision-making frameworks. Through a comparative analysis of optimal pricing strategies across different decision modes, this study provides an in-depth examination of the impact of RPE on pricing strategies and system profit deviations.

Based on the aforementioned observations, this study contributes to the literature on supply chain pricing and coordination by incorporating RPE and variations in market scale. We propose a stylized analytical model to investigate the following research questions:

(1) Under what conditions should firms implement a price increase or a price reduction strategy in response to RPE? (2) How does RPE influence pricing strategies and profit allocation within a two-tier supply chain? (3) How can contract mechanisms be designed to alleviate supply chain inefficiencies and align incentives under dynamic market conditions?

To address these issues, this study further develops a two-part tariff contract that redistributes profits between manufacturers and retailers by imposing fixed fees at different stages of sales. This mechanism effectively aligns supply chain decisions and mitigates inefficiencies in decentralized settings. Unlike traditional research, this study not only incorporates the dynamic nature of consumer behavior but also explicitly integrates variations in market scale into the model. Doing so provides a more targeted theoretical foundation as well as practical insights for dynamic pricing and contract coordination within supply chains.

2. Literature review

The research literature related to this paper mainly focuses on three aspects: reference price, two-stage pricing, and supply chain coordination.

2.1. Reference prices

Consumers' expectations of product prices are based on individual experience and market information, which is used to construct a reference price, which plays a key role when consumers evaluate new products or price changes.

Mazumdar *et al.* [40] analyzed that if the price deviates from the reference price in the minds of consumers, it may trigger a negative perception of transaction fairness, leading to a decrease in demand. Zhang *et al.* [61] pointed out that the perception of price fairness is one of the decisive factors in the consumer's purchasing decision process. Zhou *et al.* [67] pointed out that when the product's selling price exceeds the consumer's reference price, the perceived sense of loss will decrease the desire to purchase; on the contrary, if the product's selling price is below the reference price, the perceived sense of gain will enhance their intention to buy. Mehra *et al.* [41] examined reference price effects in non-durable goods markets and found a non-monotonic impact on product differentiation and firm profits. Colombo and Labrecciosa [17] explored price dynamics under competitive pressure, highlighting how reference price effects shape strategic pricing patterns. Srivastava *et al.* [50] conducted a comprehensive bibliometric analysis of reference price literature, identifying seven key research clusters and proposing future research directions to advance both theoretical development and practical applications in pricing strategies. Wang *et al.* [52] discussed the role of reference prices in new product pricing strategies, indicating that prices that are too high or too low may cause adverse reactions from consumers. Bassellier and Ramaprasad [6] noted that consumers have a certain tolerance for price changes, but if a price increase is perceived as unfair, it can reduce the willingness to purchase, even if the product itself is appealing. Chaab and Zaccour [9] analyzed the impact of anchoring effects on price perception, noting that initial price information may have a long-term impact on consumers' subsequent price evaluations.

Extensive research has shown that considering the reference price effect is decisive for constructing effective supply chain pricing strategies. This effect directly shapes consumers' perception of price adjustments and their subsequent purchasing decisions, thereby profoundly impacting the maximization of corporate profits.

Qin and Liu [48] studied the impact of the reference price effect on online product pricing and found that companies can adjust the prices of different products to guide consumers in forming reference prices that are advantageous to the business. Yan *et al.* [59] pointed out that the reference price effect significantly influences the two-stage pricing strategy in the supply chain, requiring companies to carefully consider consumers' psychological expectations in product line design and pricing decisions to maximize profits and avoid revenue losses caused by ignoring price sensitivity. Chenavaz *et al.* [14] developed a dynamic pricing model for dual-channel retailing under reference price effects, revealing how retailers optimally differentiate intertemporal prices across channels while accounting for last-mile delivery costs and consumer behavioral responses. Zhang *et al.* [64] incorporated reference prices into green supply chain contracts, showing their impact on wholesale pricing, profit allocation, and consumer surplus. Zhang *et al.* [65] studied how reference price effects impact retailers' advance selling strategies and pricing for new products to strategic consumers, deriving optimal prices and profits across scenarios. Martín-Herrán and Sigué [39] believed that considering the reference price effect of consumers is crucial for formulating effective supply chain pricing strategies because it directly affects consumers' perception of price changes and purchasing behavior. Anton *et al.* [3] pointed out that the reference price is a crucial factor affecting consumers' willingness to pay, and it influences their purchase decisions by changing their perception of the current price, emphasizing the importance of considering consumers' reference prices when formulating pricing strategies. Wang *et al.* [54] believed that companies need to consider the impact of consumers' reference prices and guide consumers effectively to form reference prices that benefit the enterprise. Wang *et al.* [56] studied the investment in cost-reducing process improvement under the reference price effect and explored the interactions between the reference price effect and process improvement in a decentralized supply chain.

2.2. Two-stage pricing

Consumer psychology and behavior play pivotal roles in the two-stage pricing strategies of supply chains, particularly in terms of acceptance and response to pricing strategies across different sales phases. The impact of pricing strategies on consumers' psychological perceptions and behavioral choices significantly influences supply chain management.

Aviv *et al.* [4] believed that adopting a two-stage dynamic pricing strategy can achieve a win–win situation for manufacturers and retailers and improve the efficiency and profitability of the entire supply chain by adjusting prices flexibly in response to market changes. Dao-ping and Yu-qing [18] also pointed out the potential negative impact of two-stage pricing on consumer perception, especially if consumers believe pricing strategies are unfair or unpredictable. Khorshidvand *et al.* [26] demonstrated that two-stage pricing enables supply chains to integrate short-term profit optimization with long-term sustainability goals, effectively balancing economic, environmental, and social objectives in closed-loop systems through coordinated pricing and operational planning. Prakash and Spann [46]'s research indicated that while dynamic pricing strategies can flexibly respond to market changes, frequent price fluctuations may weaken consumers' perception of reference prices, and retailers can take advantage of this to reduce the negative impact of reference prices on demand. Maiti [36] analyzed the interaction between product quality and pricing strategy in a two-stage supply chain model, with a focus on the impact of closed-loop supply chains and return policies on pricing. Cheng *et al.* [15] pointed out that two-stage pricing may affect consumers' sensitivity to reference prices, affecting their purchase decisions. Gu *et al.* [24] built a two-stage pricing game for duopoly freight platforms, capturing the effects of scale, commissions, and user externalities. Qi *et al.* [47] developed a two-stage pricing model for products and value-added services, revealing that consumer strategic behavior critically shapes optimal pricing decisions and that incorporating behavioral responses is essential to maximize enterprise profitability in dynamic environments.

Market demand dynamics significantly influence supply chain pricing strategies across various product life cycle stages. Businesses must comprehend and adapt to these fluctuations to ensure the efficacy of their pricing strategies and maintain competitive advantage in the marketplace.

Gönsch *et al.* [23] suggested that the dynamic nature of market demand necessitates flexible pricing adjustments to align with consumer responses. Consumers may react to high prices, affecting market performance in the subsequent maturity phase. Adeinat and Ventura [1] believed that setting higher prices during the introduction phase can establish a high-end product image, and lowering prices during the maturity phase can attract a broader consumer base. Li *et al.* [30] posited that enterprises should adopt distinct pricing strategies across various stages of a product's life cycle to accommodate fluctuations in market demand. Chen *et al.* [11] indicate that as products enter the maturity stage, there is typically a significant shift in market demand, presenting enterprises with the challenge of adjusting pricing strategies to meet market needs best. Li *et al.* [31] proposed a two-stage pricing model for nondurable goods, showing that learning effects and word-of-mouth dynamics jointly determine optimal pricing and switching time, with warranty design further enhancing profitability across product lifecycle stages. Zhang *et al.* [62] investigated two-stage pricing and greening strategies in a dual-channel supply chain, showing that dynamic pricing combined with cost-sharing contracts can improve coordination, enhance profits, and support sustainable outcomes under both centralized and decentralized decisions. Che *et al.* [10] noted that employing diverse pricing strategies is crucial for a company's market positioning during the maturity phase. Some enterprises maintain higher prices to preserve brand value and profit margins, while others may choose discounts for promotion and inventory clearance. Can-Zhong and Yi-Na [7] developed a two-stage discriminatory pricing model, showing that cross-platform externalities reshape consumer purchase timing and force platforms to adjust intertemporal pricing strategies, especially under loyalty-based price discrimination and network effects.

2.3. Supply chain coordination

In supply chain systems, firms typically prioritize maximizing their profits in the decision-making process, rather than optimizing the overall supply chain performance from a holistic perspective. This approach often leads to the double marginalization effect, which significantly harms the total profitability of the supply chain.

To mitigate the adverse effects of double marginalization, contract coordination has emerged as a widely adopted strategy in supply chain management. Extensive research shows that various contractual mechanisms can significantly enhance supply chain efficiency. For example, revenue-sharing contracts distribute profits among supply chain members according to predetermined ratios, thereby incentivizing collaboration and improving overall performance [5, 8]. In contrast, cost-sharing contracts enable firms to jointly bear costs, reducing the financial burden on individual members and enhancing resilience against market risks [25, 55]. Additionally, quantity discount contracts provide retailers with price reductions based on order volume, stimulating higher purchase quantities and realizing economies of scale [45, 63]. Finally, two-part tariff contracts, which combine fixed fees with variable pricing, are particularly effective in optimizing profit allocation among supply chain participants [2, 60].

Most existing studies explore supply chain interactions in a single-period setting. However, with rapid technological advancements, product life cycles are becoming shorter, and sales dynamics are evolving into multi-stage processes, making supply chain coordination increasingly complex. Therefore, as a transitional step from single-period to multi-period research, investigating coordination mechanisms under a two-period setting with reference price effects holds significant practical relevance.

Chueanun and Suwandechochai [16] demonstrated that in a two-period supply chain with demand uncertainty, buyback contracts can facilitate coordination between manufacturers and retailers, yet simple discount strategies often struggle to balance pricing and demand across both periods. Kumar *et al.* [27] explored a two-period supply chain model with innovation considerations and found that two-part tariff contracts could effectively coordinate decentralized supply chains. Yan and Han [58] examined a two-tier fresh agricultural supply chain, highlighting that varying cost structures and demand fluctuations across different stages can hinder the effectiveness of cost-sharing contracts in reflecting market realities. Luong and Colombathanthri [34] investigated revenue-sharing mechanisms in a three-stage supply chain but found that continuous revenue distribution compromises pricing flexibility. Li *et al.* [32] developed a two-part tariff contract model in a two-period supply chain, incorporating the influence of online reviews on pricing strategies and validating its effectiveness. Zhao and Li [66] examined pre-sale issues in dual-channel supply chains, designing a two-part tariff contract to address competitive suppression effects in the pre-sale phase.

While two-part tariff contracts have been recognized as effective mechanisms for coordinating supply chains, existing literature largely neglects the effects of reference prices. This oversight fails to consider their influence on pricing strategies and profit distribution in response to variations in market scale. Therefore, further investigation is warranted to determine whether two-part tariff contracts can continue to optimize supply chain performance in dynamic market environments when the implications of reference price effects are taken into account.

Existing research on reference prices, two-stage pricing, and supply chain coordination offers valuable insights within each respective domain; however, these studies frequently overlook the intricate interconnections among them. While the literature has extensively examined how reference price effects shape consumer behavior, it rarely investigates how these effects impact the pricing decisions of both manufacturers and retailers in a multi-period supply chain context. Similarly, investigations into two-stage pricing typically isolate price adjustment dynamics without taking into account consumers' perceptions of fairness. Furthermore, research on supply chain coordination has predominantly concentrated on single-period interactions, neglecting the complexities inherent in multi-period scenarios. This fragmented approach may lead to suboptimal pricing decisions and exacerbate issues such as double marginalization. Table 1 summarizes the closely related studies found in existing literature.

To address these gaps, our study integrates reference price effects, two-stage pricing strategies, and supply chain coordination into a cohesive dynamic framework. This integration enables us to capture the evolving nature of consumer price expectations while examining how market growth and reference price effects jointly

TABLE 1. The difference and connection between the previous literature and the research content.

Literature	Two-stage?	Decentralized/ Centralized?	Led by/ Contract type	Reference price effect?	Market Dynamics?
Ma *et al.* [35]	Yes	Both	Manufacturer/ Two-part tariff contract	No	No
Yan and Han [58]	Yes	Both	Retailer/Cost-sharing contract	No	No
Luong and Colombathanthri [34]	Yes	Both	Manufacturer/ Revenue-sharing contract	No	No
Wang *et al.* [52]	No	Centralized	Manufacturer	Yes	No
Zhang *et al.* [65]	Yes	Decentralized	Retailer	Yes	No
Chaab and Zaccour [9]	Yes	Decentralized	Manufacturer	Yes	No
Dao-ping and Yuqing [18]	Yes	Centralized	Manufacturer	No	No
Diao *et al.* [19]	Yes	Centralized	Manufacturer	Yes	Yes
This paper	Yes	Both	Manufacturer/ Two-part tariff contract	Yes	Yes

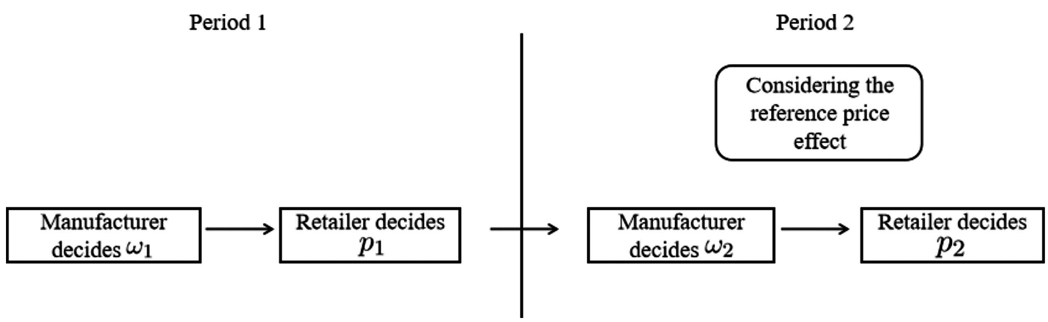

FIGURE 1. The decision sequence of the two-stage supply chain.

influence optimal pricing strategies and profit allocation under both centralized and decentralized decision-making structures. Ultimately, our findings emphasize that accounting for these interdependencies is essential for maximizing profits across the supply chain and provides more effective strategies for managing supply chains in dynamic market environments.

3. Problem description and model assumptions

Consider a supply chain system comprising one manufacturer and one retailer, where products are sold in two stages within a continuously expanding market. In each stage t ($t \in \{1, 2\}$), the manufacturer, acting as the leader in a Stackelberg game, first determines the wholesale price w_t, after which the retailer, as the follower, sets the retail price p_t. Figure 1 shows the game construct of the supply chain model.

TABLE 2. Model – related parameter symbol settings.

Symbol	Definition
M, R	Manufacturer and retailer, respectively
β	Price elasticity of demand coefficient
δ	General market demand growth
γ	Reference price effect coefficient
F	Total fixed fee paid by the retailer to the manufacturer
F2	Fixed fee paid by the retailer to the manufacturer in the second period
D_i	Demand function of the product in period i, where $i = \{1, 2\}$
w_i	Unit wholesale price of the product in period i, where $i = \{1, 2\}$
p_i	Unit retail price of the product in period i, where $i = \{1, 2\}$
π_m	Total profit of the manufacturer over two periods
π_{mi}	Profit of the manufacturer in period i, where $i = \{1, 2\}$
π_r	Total profit of the retailer over two periods
π_{ri}	Profit of the retailer in period i, where $i = \{1, 2\}$
π_{sci}	Profit of the supply chain in period i, where $i = \{1, 2\}$
π_{sc}	Total profit of the supply chain over two periods

We posit that the market demand in the initial stage is represented by $D_1 = 1 - \beta p_1$, where β signifies the price elasticity of demand – a functional form that has been extensively utilized in prior research [42, 57]. Over time, the expansion of market scale is predominantly influenced by factors such as advertising, positive word-of-mouth, and heightened consumer awareness. These elements contribute to an increase in potential market size during the second stage by an amount $\delta \geq 0$ [19]. Although δ could theoretically assume negative values to signify market contraction or failure, our emphasis lies on phases of market expansion with rising demand. Furthermore, given that market growth is frequently propelled by external and challenging-to-model influences, such as macroeconomic trends, media exposure, or network effects, we treat δ as an exogenous input. This assumption allows us to isolate and scrutinize the fundamental impact of δ on intertemporal pricing decisions and supply chain coordination.

Furthermore, when assessing demand in the second stage, some consumers take the first-stage price into account when making purchasing decisions. If the second-stage price is higher than the first-stage price, consumers may perceive unfairness, which suppresses demand. Conversely, a lower second-stage price may stimulate their willingness to purchase. This behavioral response is captured by the parameter γ $(0 < \gamma < 1)$, which reflects the intensity of the reference price effect, *i.e.*, consumers' sensitivity to the deviation between the actual price and the internal reference price [12, 49, 56]. Specifically, this formulation captures consumers' fairness concerns: when the second-stage price p_2 exceeds the first-stage price p_1, the term $\gamma(p_2 - p_1)$ becomes positive, leading to a reduction in demand due to perceived price unfairness. Hence, γ serves as a fairness sensitivity coefficient, embedding psychological price evaluations into market behavior. Accordingly, the second-stage demand is modeled as $D_2 = 1 + \delta - \beta p_2 - \gamma(p_2 - p_1)$ [37]. Without loss of generality, we normalize the manufacturer's constant marginal cost to zero [22, 43, 51]. This assumption allows for a clearer analytical focus, especially when the marginal cost is constant and does not interact with the pricing dynamics under study. While this simplification is standard in initial modeling stages, we acknowledge its limitations and suggest that future research may relax this assumption to explore more cost-sensitive environments.

For ease of description, the parameters and symbols involved in the model of this paper, along with their definitions, are presented in Table 2.

4. Benchmark model without RPE

To better identify and interpret the impact of reference price effects (RPE) on supply chain pricing, this study adopts a baseline model that excludes RPE. In this baseline model, under centralized decision-making, supply chain members determine two-stage retail prices intending to maximize total profit. Under decentralized decision-making, the manufacturer and retailer engage in a Stackelberg game to set wholesale and retail prices. The baseline model serves as a benchmark for comparison with subsequent models that incorporate RPE. This approach clearly illustrates how RPE alters supply chain pricing logic and profit distribution, highlighting their critical role in supply chain decision-making research.

4.1. Benchmark model: centralized scenario

The members of the supply chain take maximizing the total profit of the entire system as the decision-making criterion and jointly determine the retail prices of the product in the two stages. In the centralized scenario, the objective function of the supply chain decision-making is:

$$\pi_{sc} = p_1 D_1 + p_2 D_2. \tag{1}$$

By taking the derivatives concerning p_1 and p_2 simultaneously and solving the system of equations, the optimal pricing and the total profit can be obtained. The equilibrium results are summarized in Theorem 1.

Theorem 1. *Under centralized decision-making, the optimal prices in the two stages are* $p_1^{\mathrm{BC}^*} = \frac{1}{2\beta}$ *and* $p_2^{\mathrm{BC}^*} = \frac{\delta+1}{2\beta}$ *respectively. Moreover, the optimal demands and profits of the supply chain in the two stages are:* $D_1^{\mathrm{BC}^*} = \frac{1}{2}$, $D_2^{\mathrm{BC}^*} = \frac{\delta+1}{2}$, $\pi_{sc1}^{\mathrm{BC}^*} = \frac{1}{4\beta}$, $\pi_{sc2}^{\mathrm{BC}^*} = \frac{(\delta+1)^2}{4\beta}$, *and* $\pi_{sc}^{\mathrm{BC}^*} = \frac{\delta^2+2\delta+2}{4\beta}$.

Theorem 1 presents the optimal centralized pricing strategy in the absence of reference price effects. The results indicate that both optimal prices and profits increase with the market expansion parameter δ, reflecting the firm's ability to leverage growing demand over time. The price elasticity β plays a pivotal role in determining pricing power: a lower β corresponds to weaker consumer price sensitivity, enabling higher markups with limited demand reduction. As a benchmark scenario without behavioral considerations or channel inefficiencies, this result provides a clean reference point for evaluating how reference-dependent consumer behavior and decentralized decision-making may alter pricing structures and overall supply chain performance in subsequent settings.

4.2. Benchmark model: decentralized scenario

In the decentralized decision-making mode, the manufacturer and the retailer make independent decisions in each period, pursuing the maximization of their profits. They form a Stackelberg game relationship, where the manufacturer is the leader and the retailer is the follower. The decision-making process is as follows: In the first period, the manufacturer first determines the wholesale price, and the retailer sets the retail price accordingly. In the second period, the manufacturer first sets the wholesale price, and then the retailer determines the retail price. The profit situations of the supply chain members in each period are as follows:

$$\pi_{m1} = w_1 D_1 \tag{2}$$
$$\pi_{r1} = (p_1 - w_1) D_1 \tag{3}$$
$$\pi_{m2} = w_2 D_2 \tag{4}$$
$$\pi_{r2} = (p_2 - w_2) D_2. \tag{5}$$

The cumulative profits of the supply chain members in the two periods are respectively:

$$\pi_m = w_1 D_1 + w_2 D_2 \tag{6}$$
$$\pi_r = (p_1 - w_1) D_1 + (p_2 - w_2) D_2. \tag{7}$$

Theorem 2. *Under decentralized decision-making, the optimal wholesale prices and retail prices in the two stages are respectively:* $w_1^{\mathrm{BD}^*} = \frac{1}{2\beta}$, $w_2^{\mathrm{BD}^*} = \frac{1+\delta}{2\beta}$, $p_1^{\mathrm{BD}^*} = \frac{3}{4\beta}$, $p_2^{\mathrm{BD}^*} = \frac{3(1+\delta)}{4\beta}$.

The optimal demands and profits of the supply chain members in the two stages are: $D_1^{\mathrm{BD}^*} = \frac{1}{4}$, $D_2^{\mathrm{BD}^*} = \frac{\delta+1}{4}$, $\pi_m^{\mathrm{BD}^*} = \frac{\delta^2+2\delta+2}{8\beta}$, $\pi_r^{\mathrm{BD}^*} = \frac{\delta^2+2\delta+2}{16\beta}$, $\pi_{sc1}^{\mathrm{BD}^*} = \frac{3}{16\beta}$, $\pi_{sc2}^{\mathrm{BD}^*} = \frac{3(\delta+1)^2}{16\beta}$, $\pi_{sc}^{\mathrm{BD}^*} = \frac{3(\delta^2+2\delta+2)}{16\beta}$.

Theorem 2 describes the equilibrium outcomes under decentralized decision-making without reference price effects. Compared to the centralized case, retail prices are consistently higher, while demands are reduced to one-half of the centralized level. This reflects the classic double marginalization effect: both the manufacturer and the retailer add their markups, leading to inflated retail prices and suppressed demand. Consequently, supply chain profit is strictly lower than in the centralized benchmark, and this inefficiency grows more severe as the market expands.

Proposition 1. *When the reference price effect is not considered, the following relationships exist among the equilibrium results of the optimal prices and profits in the two stages under the two decision-making modes:*

(1) $p_1^{\mathrm{BC}^*} < p_2^{\mathrm{BC}^*}$; $D_1^{\mathrm{BC}^*} < D_2^{\mathrm{BC}^*}$; $\pi_{sc1}^{\mathrm{BC}^*} < \pi_{sc2}^{\mathrm{BC}^*}$.
(2) $p_1^{\mathrm{BD}^*} < p_2^{\mathrm{BD}^*}$; $w_1^{\mathrm{BD}^*} < w_2^{\mathrm{BD}^*}$; $D_1^{\mathrm{BD}^*} < D_2^{\mathrm{BD}^*}$; $\pi_{m1}^{\mathrm{BD}^*} < \pi_{m2}^{\mathrm{BD}^*}$; $\pi_{r1}^{\mathrm{BD}^*} < \pi_{r2}^{\mathrm{BD}^*}$.
(3) $\pi_{sc1}^{\mathrm{BC}^*} > \pi_{sc1}^{\mathrm{BD}^*}$; $\pi_{sc2}^{\mathrm{BC}^*} > \pi_{sc2}^{\mathrm{BD}^*}$; $\pi_{sc}^{\mathrm{BC}^*} > \pi_{sc}^{\mathrm{BD}^*}$.

Proposition 1 indicates the following: (1) When neglecting RPE, as market scale increases, both centralized and decentralized decision-making result in a retail price in the second stage that is higher than that in the first stage; (2) In a decentralized decision-making framework, both manufacturers and retailers aim to maximize their profits. The presence of double marginalization leads to both wholesale and retail prices being elevated compared to those under centralized decision-making. Additionally, the manufacturer maintains a relatively low wholesale price during the first stage to incentivize increased procurement by the retailer; (3) Following an expansion of market scale, the manufacturer raises its wholesale price to further enhance profit margins. However, this incremental pricing strategy exacerbates cost pressures on retailers, suppresses overall market demand, and ultimately results in a lower total profit for the supply chain compared to that achieved under centralized decision-making.

5. Supply chain decision-making with RPE

In this section, we conduct an in-depth exploration of the impact of RPE on supply chain decision-making. Similar to Section 4, we first examine both centralized and decentralized decision-making models, comparing pricing strategies and profit distributions across different models in a two-stage supply chain. Finally, we design coordination contracts to further enhance the economic performance of the decentralized supply chain. All models are solved using the backward induction method to determine the optimal decisions for the two-stage supply chain.

5.1. Centralized scenario

The game process considering the RPE is similar to that in Section 4.1, and the equilibrium results are summarized in Theorem 3.

Theorem 3. *Under centralized decision-making scenario, the optimal prices in the two stages are* $p_1^{C^*} = \frac{2\beta+3\gamma+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$ *and* $p_2^{C^*} = \frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$ *respectively. Moreover, the optimal demands and profits of the supply chain in the two stages are:* $D_1^{C^*} = 1 - \frac{\beta(2\beta+3\gamma+\delta\gamma)}{4\beta^2+4\beta\gamma-\gamma^2}$, $D_2^{C^*} = \frac{(\beta+\gamma)(2\beta+2\beta\delta+\gamma)}{4\beta^2+4\beta\gamma-\gamma^2}$, $\pi_{sc1}^{C^*} = \frac{4\beta^3+8\beta^2\gamma-\beta\delta^2\gamma^2-2\beta\delta\gamma^2+\beta\gamma^2-\delta\gamma^3-3\gamma^3}{(4\beta^2+4\beta\gamma-\gamma^2)^2}$, $\pi_{sc2}^{C^*} = \frac{(\beta+\gamma)(2\beta+2\beta\delta+\gamma)^2}{(4\beta^2+4\beta\gamma-\gamma^2)^2}$, $\pi_{sc}^{C^*} = \frac{2\beta+2\beta\delta+2\gamma+\beta\delta^2+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$.

Theorem 3 illustrates how reference price effects influence centralized pricing and demand allocation over time. When consumers anchor their expectations to prior prices, firms face the strategic challenge of managing intertemporal consistency in pricing. A higher sensitivity to reference prices encourages firms to set a stronger initial price signal, effectively shaping consumers' future valuation. This behavior shifts a portion of demand from the first stage to the second, as consumers interpret subsequent prices relative to the initial anchor. However, this demand reallocation only enhances total profitability when the market is sufficiently expanding; otherwise, the early-stage loss may not be fully recovered. Importantly, the effect of reference price sensitivity on profit is nonlinear: it can either undermine or support profit maximization depending on the growth rate of the market. These findings underscore the importance of coordinating pricing decisions over time and accounting for consumer reference dependence in dynamic market environments.

Proposition 2. *Under a centralized decision-making scenario, the influence of the reference price coefficient* γ *affects the retail prices and profits in the two stages:* $\frac{\partial p_1^{C^*}}{\partial \gamma} > 0$*;* $\frac{\partial p_2^{C^*}}{\partial \gamma} > 0$*, if* $\delta > \frac{-4\beta^2+4\beta\gamma+\gamma^2}{8\beta^2-4\beta\gamma}$*;* $\frac{\partial \pi_{sc}^{C^*}}{\partial \gamma} > 0$*, if* $\delta > \frac{2\gamma}{2\beta-\gamma}$.

Proposition 2 suggests that, within the framework of centralized decision-making, the retail price in the initial stage is positively correlated with RPE. Enterprises typically opt to set a relatively high price during this first stage to influence consumers' perception of prices and subsequently achieve enhanced returns by capitalizing on the reference price effect in the second stage. When market scale growth δ is modest, there is an observable decline in retail prices during the second stage as RPE increases, aimed at sustaining demand. Conversely, when market scale experiences substantial growth, enterprises are positioned to leverage RPE to elevate prices in the second stage and thereby capitalize on market expansion. Furthermore, under specific conditions on market scale growth δ, an increase in RPE can lead to an overall enhancement of profits within the supply chain.

Proposition 3. *Under centralized decision-making, when not considering the RPE and considering the RPE, the following relationships exist among the equilibrium results of the optimal prices and profits in the two stages under the two decision-making modes:*

(1) $p_1^{\mathrm{BC}^*} < p_1^{C^*}$*;* $p_2^{\mathrm{BC}^*} > p_2^{C^*}$*, if* $0 < \gamma < \frac{2\beta(2\delta+1)}{\delta+1}$*;* $D_1^{\mathrm{BC}^*} > D_1^{C^*}$*;* $D_2^{\mathrm{BC}^*} < D_2^{C^*}$.
(2) $\pi_{sc}^{\mathrm{BC}^*} > \pi_{sc}^{D^*}$*, if* $0 < \gamma < \frac{4\beta\delta(\delta+1)}{\delta^2+2\delta+2}$.

Proposition 3 suggests that when considering RPE, the supply chain sets a higher retail price initially. This strategy creates a reference point for consumers, making later price reductions seem more attractive and stimulating second-stage demand. In contrast, without RPE, consumer decisions in the first stage are less affected by past prices, leading to higher immediate demand. However, under RPE, while a high initial price anchors expectations, it also suppresses first-stage demand. This shift redistributes demand to the second stage and enhances purchases during that period. Although leveraging RPE can boost second-stage demand, any benefits may not offset profit losses from reduced first-stage sales – especially when RPE is weak and consumers show lower sensitivity to historical pricing. Consequently, the effectiveness of pricing strategies declines and overall supply chain profitability suffers.

5.2. Decentralized scenario

The game process considering the RPE is similar to that in Section 4.2, and the equilibrium results are summarized in Theorem 4.

Theorem 4. *Under decentralized decision-making, the optimal wholesale prices and retail prices in the two stages are respectively:* $w_1^{D^*} = \frac{1}{2\beta}$, $w_2^{D^*} = \frac{\beta+\beta\delta+\gamma}{2\beta(\beta+\gamma)}$, $p_1^{D^*} = \frac{6\beta^2-\gamma^2+7\beta\gamma+\beta\delta\gamma}{8\beta^3+8\beta^2\gamma-2\beta\gamma^2}$, $p_2^{D^*} = \frac{6\beta^3\delta+6\beta^3-\gamma^3+4\beta\gamma^2+11\beta^2\gamma+6\beta^2\delta\gamma-\beta\delta\gamma^2}{8\beta^4+16\beta^3\gamma+6\beta^2\gamma^2-2\beta\gamma^3}$.

Under decentralized decision-making, the optimal demands and supply chain profits in the two stages are respectively: $D_1^{D^*} = \frac{2\beta^2-\gamma^2+\beta\gamma-\beta\delta\gamma}{8\beta^2+8\beta\gamma-2\gamma^2}$, $D_2^{D^*} = \frac{(\beta+\gamma)(2\beta+2\beta\delta+\gamma)}{2(4\beta^2+4\beta\gamma-\gamma^2)}$, $\pi_m^{D^*} = \frac{2\beta+2\beta\delta+2\gamma+\beta\delta^2+\delta\gamma}{8\beta^2+8\beta\gamma-2\gamma^2}$, $\pi_r^{D^*} = \frac{2\beta+2\beta\delta+2\gamma+\beta\delta^2+\delta\gamma}{16\beta^2+16\beta\gamma-4\gamma^2}$, $\pi_{sc1}^{D^*} = \frac{(2\beta^2-\beta\gamma(\delta-1)-\gamma^2)(6\beta^2+\beta\gamma(7+\delta)-\gamma^2)}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)^2}$, $\pi_{sc2}^{D^*} = \frac{(2\beta(1+\delta)+\gamma)(6\beta^3(1+\delta)+\beta^2\gamma(11+6\delta)}{4\beta(4\beta^2+4\beta\gamma-\gamma^2}$, $\pi_{sc}^{D^*} = \frac{3(2\beta+2\beta\delta+2\gamma+\beta\delta^2+\delta\gamma)}{4(4\beta^2+4\beta\gamma-\gamma^2)}$.

Theorem 4 reflects the strategic pricing adjustments firms make in response to evolving consumer sensitivity and inter-temporal demand effects. The prices and demands exhibit the complex interplay between stages, where an increase in market scale generally raises both prices and quantities, but cross-stage demand interactions impose constraints that prevent unbounded growth. Profit functions for manufacturers and retailers similarly depend on these parameters, illustrating the balance each player strikes between maximizing their returns and reacting to competitive and cooperative pressures within the supply chain.

Proposition 4. *Under decentralized decision-making, the influence of the reference-price coefficient γ effect on two-stage pricing and profits is as follows:*

(1) $\frac{\partial w_1^{D^*}}{\partial\gamma}=0$; $\frac{\partial w_2^{D^*}}{\partial\gamma}<0$; $\frac{\partial \pi_M^{D^*}}{\partial\gamma}>0$, *if* $\delta>\frac{2\gamma}{2\beta-\gamma}$.

(2) $\frac{\partial p_1^{D^*}}{\partial\gamma}>0$; $\frac{\partial p_2^{D^*}}{\partial\gamma}>0$, *if* $\delta>\frac{(\beta+\gamma(-4\beta^2+4\beta\gamma+\gamma^2)}{24\beta^4+44\beta^3\gamma+8\beta^2\gamma^2-12\beta\gamma^3+\gamma^4}$; $\frac{\partial \pi_R^{D^*}}{\partial\gamma}>0$, *if* $\delta>\frac{2\gamma}{2\beta-\gamma}$.

Proposition 4 indicates that the manufacturer's first-stage wholesale price is unaffected by the RPE, following a similar pattern without this effect. This occurs because the manufacturer does not use wholesale price adjustments to influence consumers' price perceptions. However, in the second stage, the wholesale price decreases as RPE strengthens. This reduction incentivizes retailers to increase procurement by lowering prices, thereby alleviating negative consumer reactions to price hikes. Moreover, when market expansion is limited, the negative effects of RPE are more pronounced. In these situations, retailers tend to maintain or reduce retail prices for competitiveness rather than raising them. Only with a sufficiently large market size can RPE provide additional benefits for firms; otherwise, reference price sensitivity may necessitate price cuts and diminish profitability.

Proposition 5. *Under decentralized decision-making, when not considering the RPE and considering the RPE, the following relationships exist among the equilibrium results of the optimal prices and profits in the two stages under the two decision-making modes:*

(1) $p_1^{\mathrm{BD}^*}<p_1^{D^*}$; $p_2^{\mathrm{BD}^*}>p_2^{D^*}$, *if* $\delta>\frac{\gamma^2-2\beta^2-\beta\gamma}{12\beta^2+11\beta\gamma-3\gamma^2}$; $w_1^{\mathrm{BD}^*}=w_1^{D^*}$; $w_2^{\mathrm{BD}^*}>w_2^{D^*}$; $D_1^{\mathrm{BD}^*}>D_1^{D^*}$; $D_2^{\mathrm{BD}^*}<D_2^{D^*}$.

(2) $\pi_{sc}^{\mathrm{BD}^*}>\pi_{sc}^{D^*}$, *if* $0<\gamma<\frac{4\beta\delta(\delta+1)}{\delta^2+2\delta+2}$.

Proposition 5 shows that without the RPE, firms typically set a lower initial price to attract demand and then raise prices in line with market growth trends. However, when considering the RPE, retailers tend to increase prices initially to reduce negative consumer perceptions during the first stage. Additionally, manufacturers aim to stabilize supply chain relationships early on and avoid premature price changes that could disrupt retailers' procurement strategies; thus, wholesale prices remain unchanged in the first stage. In contrast, wholesale prices rise significantly in the second stage as manufacturers apply greater cost pressure on retailers by increasing these prices after accounting for the RPE. This forces retailers to adopt conservative pricing strategies to mitigate potential profit losses from miscalculations. From a market demand dynamics perspective, the RPE greatly affects demand distribution over time. Without it, first-stage demand is higher; however, its presence reduces demand during this period while reversing this trend in the subsequent stage.

Furthermore, when the RPE is weak, total profits without its consideration exceed those with it included. This occurs because limited demand growth fails to offset declining marginal profits, ultimately reducing overall profitability. As a result, retailers adopt conservative pricing strategies. Even with a weak RPE, they must consider consumers' historical price references, which restricts their ability to increase demand through price cuts. In contrast, models that exclude the RPE provide firms greater flexibility in optimizing profits based on market demand, leading to higher overall profitability.

Proposition 6. *Considering the RPE, the following relationships exist among the equilibrium results of the optimal prices and profits in the two stages under the two decision-making modes:*

(1) $p_1^{C^*}>p_2^{C^*}$, *if* $0<\delta<\frac{2\gamma}{2\beta-\gamma}$; $D_1^{C^*}<D_2^{C^*}$; $\pi_{sc1}^{C^*}<\pi_{sc2}^{C^*}$.

(2) $p_1^{D^*}>p_2^{D^*}$, *if* $0<\delta<\frac{2\gamma(\beta+\gamma)}{6\beta^2+5\beta\gamma-2\gamma^2}$; $w_1^{D^*}<w_2^{D^*}$; $D_1^{D^*}<D_2^{D^*}$; $\pi_{m1}^{D^*}<\pi_{m2}^{D^*}$; $\pi_{r1}^{D^*}<\pi_{r2}^{D^*}$.

(3) $\pi_{sc1}^{C^*} > \pi_{sc1}^{D^*}$, *if* $0 < \delta < \frac{2\beta^2+\beta\gamma-\gamma^2}{\beta\gamma}$; $\pi_{sc1}^{C^*} > \pi_{sc1}^{D^*}$; $\pi_{sc2}^{C^*} > \pi_{sc2}^{D^*}$; $\pi_{sc}^{C^*} > \pi_{sc}^{D^*}$.

Proposition 6 delineates the equilibrium conditions for optimal two-stage pricing and profit allocation, emphasizing distinct pricing strategies. The supply chain employs price discrimination to maximize revenue across varying market conditions. When market expansion is constrained, overall demand growth becomes limited, resulting in heightened price sensitivity among consumers. In such circumstances, firms are inclined to lower retail prices to stimulate consumer demand while capitalizing on economies of scale and establishing reduced reference prices. Manufacturers also decrease wholesale prices to incentivize retailers' procurement efforts, thereby enhancing overall profitability within the supply chain. Conversely, when market expansion is substantial, the adverse effects of reference prices on consumer behavior diminish due to an increase in total demand. Firms can then implement moderate price increases aimed at enhancing per-unit profitability. Furthermore, elements such as brand perception and consumer preference for high-quality products mitigate resistance to price hikes. Although some consumers may exhibit hesitance towards elevated prices, the overall sales volume remains robust – enabling firms to optimize total supply chain profits through strategic pricing adjustments.

The analysis underscores the inefficiencies inherent in decentralized decision-making when compared to centralized coordination. In decentralized systems, manufacturers and retailers independently optimize their profits, frequently neglecting the advantages associated with supply chain integration. This misalignment exacerbates double marginalization, leading to elevated wholesale and retail prices that diminish consumer demand and overall efficiency. In contrast, centralized decision-making facilitates unified pricing strategies that align incentives throughout the supply chain, thereby minimizing inefficiencies. To enhance profitability within decentralized frameworks, it is essential to implement contractual mechanisms designed to improve coordination among participants. Such mechanisms can mitigate pricing distortions, foster alignment among supply chain stakeholders, and ultimately optimize system-wide profits.

5.3. Two-part tariff contract

To coordinate a supply chain with two-stage pricing and dynamic market conditions, a contract with intertemporal flexibility is essential. The two-part tariff contract is particularly suitable as it differentiates sales incentives set by the wholesale price from profit distribution determined by the fixed fee, enabling effective coordination across periods. Its structure ensures both analytical tractability and temporal control. Given its demonstrated effectiveness in multi-period settings [27, 28, 32], we adopt this contract in our model.

In the two-stage supply chain scenario with decentralized decision-making and considering the RPE, this section aims to achieve effective coordination of the supply chain by constructing a two-part tariff contract mechanism. In each stage, the manufacturer first determines the wholesale price of the product and then charges a fixed fee from the retailer. Assume that the total fixed fee the manufacturer collects from the retailer in the two stages is F. If the fixed fee the retailer pays to the manufacturer in the second stage is F_2, then in the first stage, the fixed fee the retailer needs to pay is $F - F_2$. The following are the specific profits of the supply chain members in different stages:

$$\pi_{m_1} = w_1 D_1 + F_1 \tag{8}$$

$$\pi_{r_1} = (p_1 - w_1) D_1 - F_1 \tag{9}$$

$$\pi_{m_2} = w_2 D_2 + F_2 \tag{10}$$

$$\pi_{r_2} = (p_2 - w_2) D_2 - F_2. \tag{11}$$

The cumulative profits of the supply chain members in the two stages are as follows:

$$\pi_m = w_1 D_1 + w_2 D_2 + F \tag{12}$$

$$\pi_r = (p_1 - w_1) D_1 + (p_2 - w_2) D_2 - F. \tag{13}$$

Theorem 5. *Under the two-part tariff contract, the optimal wholesale prices, retail prices, manufacturer and retailer profits, and the fixed fees* $\{F_1, F_2\}$ *that can coordinate the supply chain are respectively:* $w_1^{T^*} = \frac{\gamma(2\beta+2\beta\delta+\gamma)}{\beta(4\beta^2+4\beta\gamma-\gamma^2)}$, $w_2^{T^*} = 0$, $p_1^{T^*} = p_1^{C^*} = \frac{2\beta+3\gamma+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$, $p_2^{T^*} = p_2^{C^*} = \frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$, $\pi_m^{T^*} = F + \frac{\gamma(2\beta^2-\gamma^2+\beta(\gamma-\gamma\delta))\gamma(2\beta+2\beta\delta+\gamma)}{\beta(-4\beta^2-4\beta\gamma+\gamma^2)^2}$,

$$\begin{aligned}\pi_r^{T^*} &= \frac{-16F\beta^5 + \gamma^4 - \beta\gamma^3(1 + F\gamma - 2\delta)}{\beta(-4\beta^2 - 4\beta\gamma + \gamma^2)^2} \\ &+ \frac{4\beta^4(2 - 8F\gamma + \delta(2 + \delta)) + 4\beta^3\gamma(3 - 2F\gamma + \delta(2 + \delta)) + \beta^2\gamma^2(2 + 8F\gamma + \delta(2 + \delta))}{\beta(-4\beta^2 - 4\beta\gamma + \gamma^2)^2}\end{aligned}$$

$$\begin{cases} F_1^* + F_2^* > \dfrac{\beta(4\beta^2 + 4\beta\gamma - \gamma^2)(\gamma(2 + \delta) + \beta(2 + 2\delta + \delta^2)) + 2\gamma(\gamma^2 - 2\beta^2 + \beta\gamma(\delta - 1))(\gamma + 2\beta(1 + \delta))}{2\beta(4\beta^2 + 4\beta\gamma - \gamma^2)^2} \\ F_1^* + F_2^* < \dfrac{4\gamma^4 + \beta\gamma^3(9\delta - 2) + 12\beta^4(2 + \delta(2 + \delta)) + 4\beta^3\gamma(8 + \delta(5 + 3\delta)) + \beta^2\gamma^2(2 + \delta(6 + 5\delta))}{4\beta(4\beta^2 + 4\beta\gamma - \gamma^2)^2}. \end{cases}$$

Theorem 5 demonstrates that after introducing the two-part tariff contract, the manufacturer sets the second-stage wholesale price to zero and collects part of the revenue in the form of a fixed fee. This approach avoids profit losses and demand suppression caused by step-by-step price increases, effectively eliminating the double-marginalization effect. Moreover, in the second-stage market, the RPE has a more significant impact on consumer demand. By reducing the second-stage wholesale price, the manufacturer provides the retailer with a cost advantage, enabling the retailer to attract more consumers by lowering the retail price and thus expanding demand. The manufacturer compensates for the loss of wholesale revenue through the fixed-fee part of the contract to maximize its profit. The retailer implements differential retail pricing based on market dynamics, which significantly increases the second-stage market demand and the overall system profit, reaching the optimal level under centralized decision-making. Given this, the manufacturer should consider the cooperation issues in the supply chain when making two-stage product pricing decisions.

In summary, when the price settings satisfy $p_1^{T^*} = p_1^{C^*}$, $p_2^{T^*} = p_2^{C^*}$ and the contract parameters take the values of $w_1^{T^*} = \frac{\gamma(2\beta+\gamma+2\beta\delta)}{\beta(4\beta^2+4\beta\gamma-\gamma^2)}$, $w_2^{T^*} = 0$, F_1^* and F_2^*, the two-part tariff contract is highly effective in coordinating the supply chain operations. In addition, the contract yields a feasible interval for the fixed fee, within which the payment from the retailer to the manufacturer can be negotiated. When the fixed fee reaches its upper bound, the retailer's profit can only reach the level achieved under decentralized decision-making, while the manufacturer captures the coordination surplus. Conversely, when the fixed fee approaches its lower bound, it is the manufacturer's profit that can only match the decentralized outcome, allowing the retailer to improve its profit through lower procurement costs.

6. Numerical analyses

To further explore the influence of the RPE on optimal two-stage decision-making and the design of a coordinated two-stage contract, this section conducts numerical experiments to derive managerial implications. Combined with previous literature and the parameter range of this study, the parameter settings are as follows: $\beta = 0.6$, reflecting a moderately price-sensitive market and aligning with common elasticity estimates in the pricing literature [10,11]; γ is assumed to lie in the interval $[0, 1]$, which is a standard setting in the behavioral pricing literature [39,56]; and δ is assumed to lie in the interval $[0.25, 0.55]$, capturing moderate market growth across product life cycle stages, consistent with prior studies [19].

6.1. Impact of RPE on supply chain profitability

As can be seen from Figure 2, only when the reference-price effect is strong and the market expands rapidly does the centralized profit without considering the reference-price effect fall below that considering the reference-price effect. This indicates that, in most cases (when γ is small), the reference-price effect will erode the supply-chain profit. Regardless of the value of γ, taking the reference-price effect into account will lead to a decrease

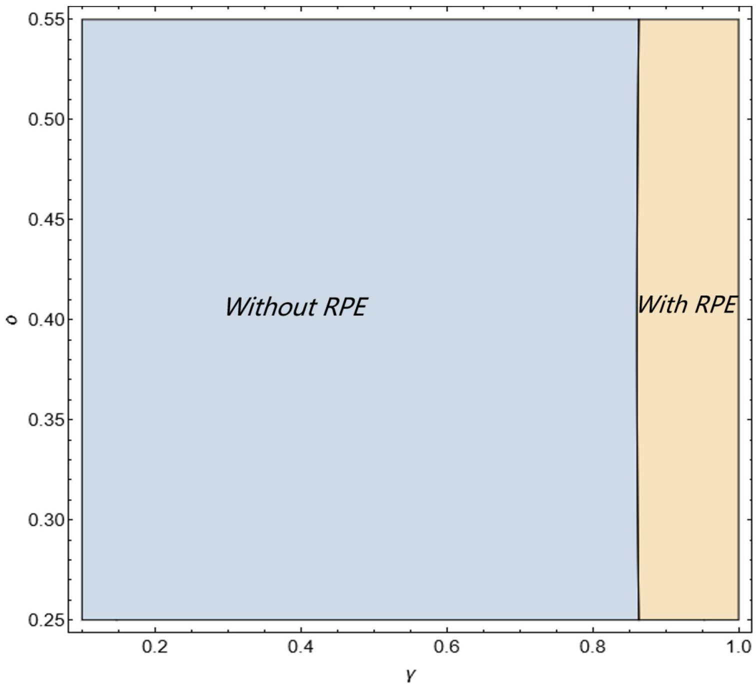

FIGURE 2. Profit comparison of centralized supply chain with and without RPE.

in the supply-chain profit. Therefore, during the introduction stage, enterprises should refrain from relying on the reference-price effect and instead adopt a market-penetration pricing strategy.

Figure 3 demonstrates analogous trends under decentralized decision-making. At low γ values, historical pricing exerts minimal influence, such that neglecting the RPE yields higher profits. As γ increases, however, the RPE fosters more stable consumer expectations and elevates willingness to pay – an outcome particularly pronounced when the market scale is substantial. By contrast, in contexts of moderate market growth, overreliance on RPE may yield counterproductive results. These findings suggest that flexible pricing strategies are optimal at low γ, whereas a stable, high-anchor pricing framework becomes feasible only under conditions of strong RPE combined with significant market expansion.

6.2. Optimal pricing strategy under different decision modes

Figure 4 illustrates the optimal pricing strategy under varying market conditions. When δ is high, indicating strong market growth and γ is moderate, a price-increase strategy is optimal. A larger market suggests a growing consumer base where additional demand from new consumers can offset losses from higher prices, leading to profit growth. Furthermore, with moderate γ, consumers are more tolerant of price increases, reducing the risk of significant demand decline. Conversely, when δ is low and γ falls within another range, a price-decrease strategy becomes more effective. In constrained markets where demand growth is limited, consumers become more price-sensitive. A higher γ heightens reliance on past prices; even minor increases may deter purchases. Thus, lowering prices enhances competitiveness and attracts price-sensitive consumers while helping firms maintain or grow their market share despite limited expansion opportunities.

Figure 5 illustrates that in the decentralized scenario, area division differs from the centralized case due to variations in decision-making. Decentralized settings generally lead to higher prices and lower efficiency, limiting strategies for price increases or decreases. The larger "Price decrease strategy" area indicates that reducing prices in the second stage is more prevalent. Multiple decision-makers hinder market growth; for

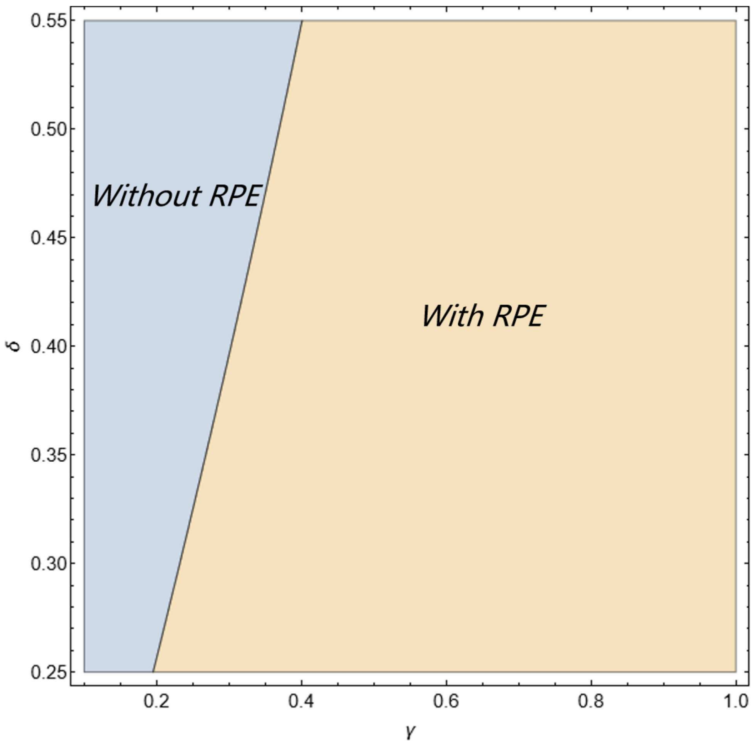

FIGURE 3. Profit comparison of decentralized supply chain with and without RPE.

instance, retailers facing fierce competition become highly price-sensitive without full supply-chain coordination. Conversely, the smaller "Price increase strategy" area shows that decentralized supply chains seldom identify profitable opportunities for price increases. Fragmented decision-making can result in missed chances despite favorable δ and γ. Entities' optimizations often conflict with overall supply-chain pricing goals, making price-increase strategies more cautious.

6.3. Influence of RPE on two-stage pricing decisions

Figure 6 illustrates the optimal pricing strategies under centralized decision-making. When $\gamma < 0.286$, the "Price increase strategy" ($p_1^{C^*} < p_2^{C^*}$) is optimal. A weak reference price effect means consumers are less influenced by past prices, making the market more accepting of price hikes. As the market expands, firms can raise prices in the second stage, leveraging new demand to offset potential customer loss and boosting profitability. Conversely, when $\gamma > 0.286$, the "Price decrease strategy" ($p_1^{C^*} > p_2^{C^*}$) is preferable. A stronger reference price effect makes consumers highly sensitive to price fluctuations, leading them to compare current prices with past ones. In this case, raising prices risks significant customer attrition. Lowering prices in the second stage helps attract price-sensitive consumers, enhancing competitiveness and sustaining market share.

Figure 7 illustrates optimal pricing strategies in a decentralized context. When $\gamma < 0.697$, the "Price Increase Strategy" ($p_1^{D^*} < p_2^{D^*}$) is preferred, as lower values of γ reduce the reference price effect and consumer sensitivity to historical prices. In contrast to centralized systems, where pricing aligns with supply chain goals, decentralized decision-making involves independent manufacturers and retailers aiming for individual profit maximization. This leads to coordination challenges when implementing a second-stage price increase that could hinder overall supply chain efficiency. When $\gamma > 0.697$, the "Price Decrease Strategy" ($p_1^{D^*} > p_2^{D^*}$) becomes optimal due to an increased reference price effect that makes consumers more sensitive to current *versus* past prices. Fragmented

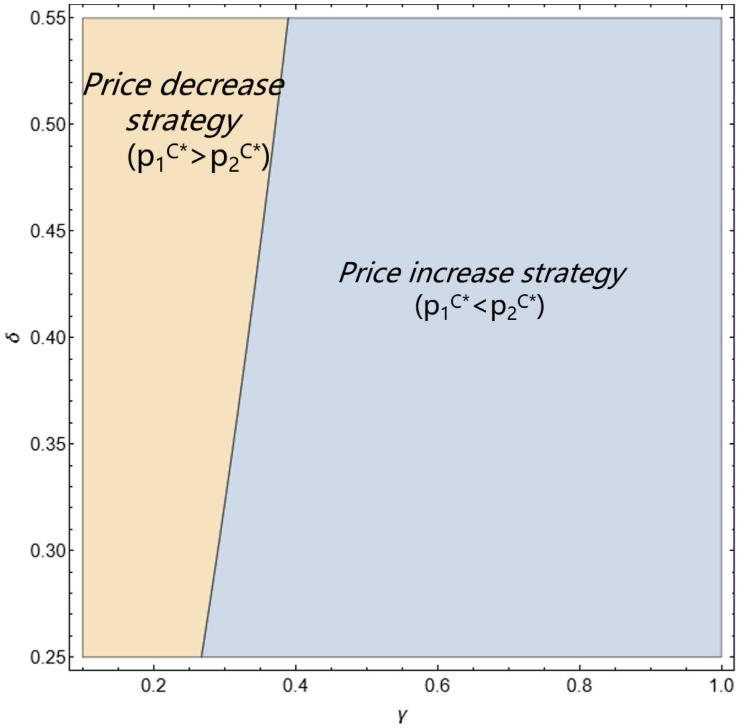

FIGURE 4. Strategy choice *versus* γ and δ under centralized decision-making.

decision-making in decentralized frameworks can result in misaligned pricing strategies as entities prioritize their gains over collective efficiency. Unlike centralized settings where pricing decisions are coordinated for total profit optimization, a second-stage price reduction focuses on retaining price-sensitive consumers and maintaining market share.

6.4. Impact of γ on market demand and supply chain profits

Figure 8 illustrates that, in centralized decision-making, market demand peaks in the second stage, whereas it is lowest in the first stage under decentralized decision-making. As γ increases, demand fluctuates over time: first-stage demand gradually declines while second-stage demand rises, widening the gap between them. In centralized scenarios, the reference price effect enhances second-stage demand and negatively impacts first-stage demand more than in decentralized scenarios. Despite harming initial product demand, from a broader supply chain perspective, the reference price effect positively influences total demand across both stages.

Figure 9 shows that the reference price effect initially reduces supply chain profitability in the first stage, but leads to greater positive impacts in the second stage, resulting in an overall profit increase. To counteract this negative impact in the second stage, firms often set higher initial prices to create a price anchor. While this may suppress some demand initially, it positions the second-stage price as a "discount" or "better deal", enhancing consumers' willingness to purchase and stimulating demand for profit growth. Additionally, centralized pricing coordination alleviates double marginalization compared to decentralized decision-making, further boosting supply chain profitability and operational efficiency. By optimizing pricing strategies across both stages, centralized coordination maximizes long-term supply chain value while balancing short-term constraints with sustained revenue growth.

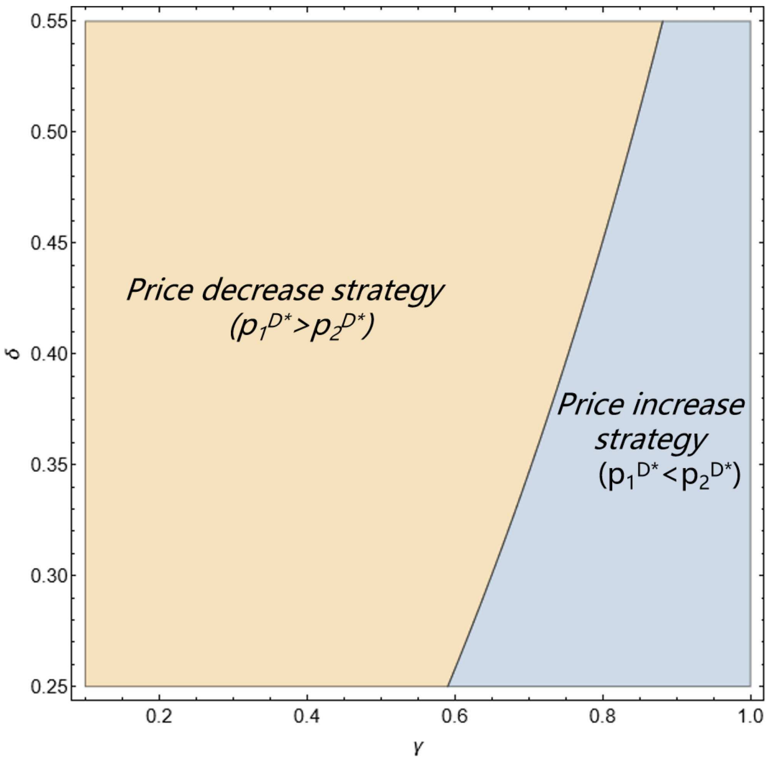

FIGURE 5. Strategy choice *versus* γ and δ under decentralized decision-making.

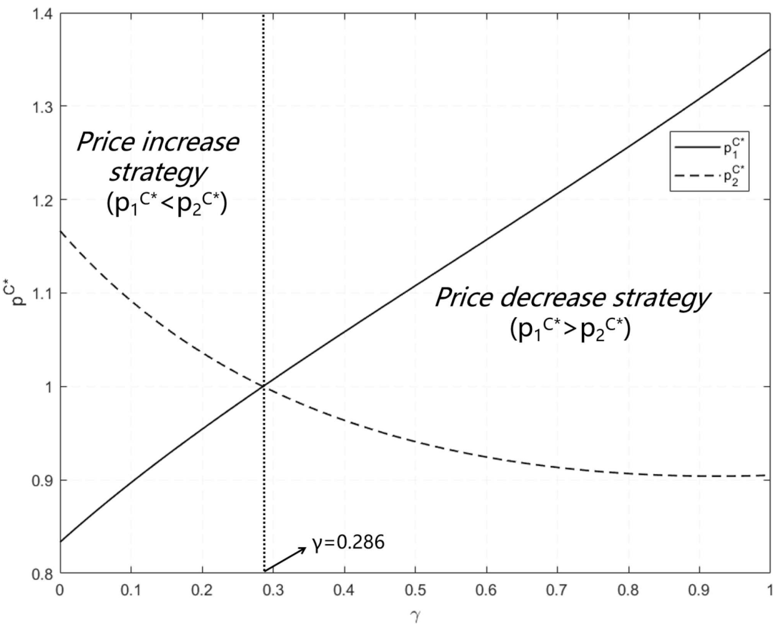

FIGURE 6. Influence of γ on two-stage prices under centralized decision-making.

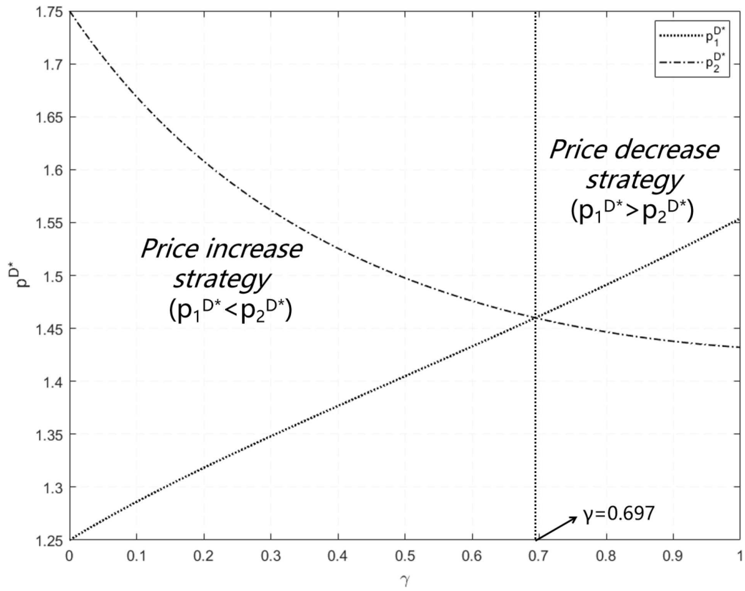

FIGURE 7. Influence of γ on two-stage prices under decentralized decision-making.

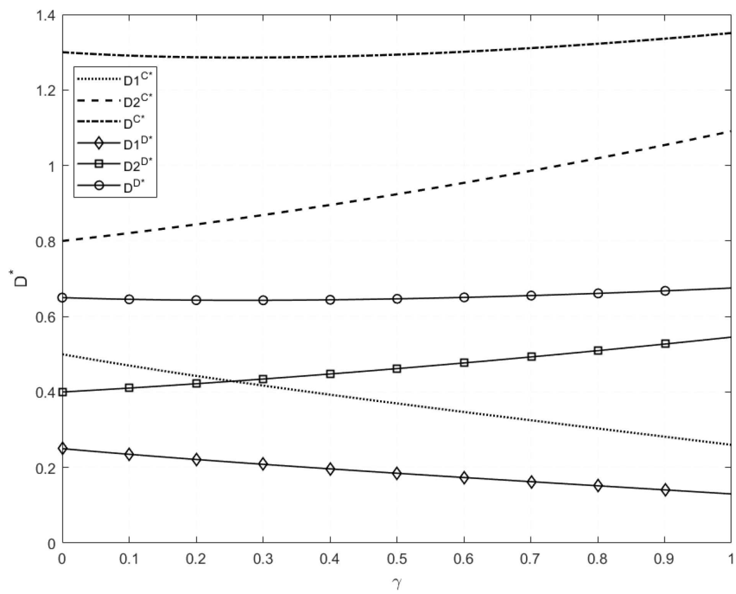

FIGURE 8. Impact of γ on market demand.

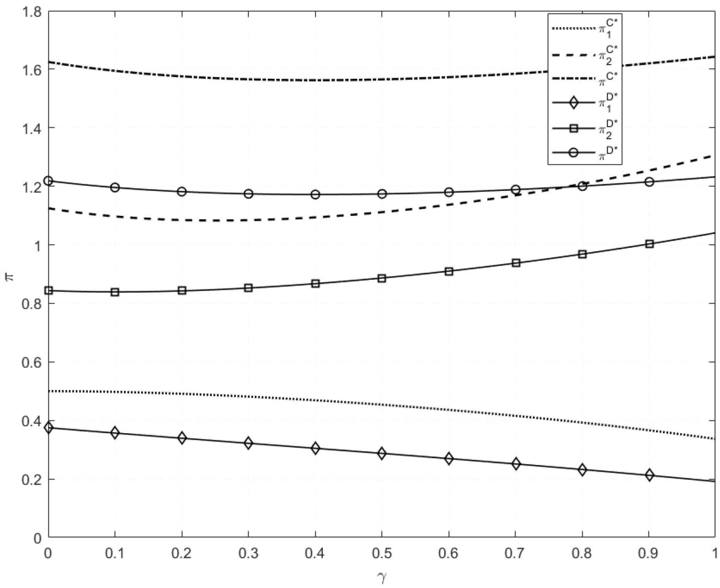

FIGURE 9. Impact of γ on supply chain profits.

6.5. Impact of two-part tariff contracts on pricing and profit distribution

Figure 10 shows that under decentralized decision-making, the wholesale price in the first stage is unaffected by the RPE. This stability is mainly due to manufacturers' focus on maintaining stable market relationships during this phase. By avoiding significant price fluctuations, they aim to keep retailers motivated to purchase, as erratic pricing could discourage procurement decisions. In contrast, in the second stage, manufacturers skillfully leverage the reference price effect to adjust their pricing strategies and capitalize on future demand growth for optimal profit margins. Additionally, the first-stage wholesale price $w_1^{T^*}$ becomes significantly more stable with increasing γ, while the second-stage wholesale price $w_2^{T^*}$ remains at zero. This difference arises because manufacturers primarily recover profits through fixed fees, allowing them to set a zero second-stage wholesale price and eliminate double marginalization effects. This arrangement provides retailers with greater pricing flexibility and enables them to adopt more aggressive competitive strategies that stimulate market demand.

Figure 11 demonstrates that the fixed fee F in a two-part tariff contract is pivotal in determining profit distribution between supply chain members. As F increases, the manufacturer captures more surplus through the fixed payment, while the retailer's profit declines due to reduced marginal benefits. Importantly, a win–win outcome emerges when $F \in [0.416, 0.728]$, where both manufacturer and retailer achieve higher profits than under decentralized decision-making. Outside this range, the coordination effect deteriorates: if F is too low, the manufacturer's profit falls short of its decentralized benchmark, and if too high, the retailer lacks incentive to participate. This finding highlights that profit-sharing must be carefully calibrated to sustain stable and cooperative relationships. Setting F within the win–win interval enables effective coordination while maintaining fairness and mutual benefit, offering a practical reference for firms designing pricing contracts in dynamic and competitive markets.

6.6. Managerial contributions

In summary, the managerial implications are as follows:

(1) During the transition from the introduction to maturity stage, firms should dynamically adjust their pricing strategies. In markets with slow growth or high consumer sensitivity to price fluctuations, a price reduction

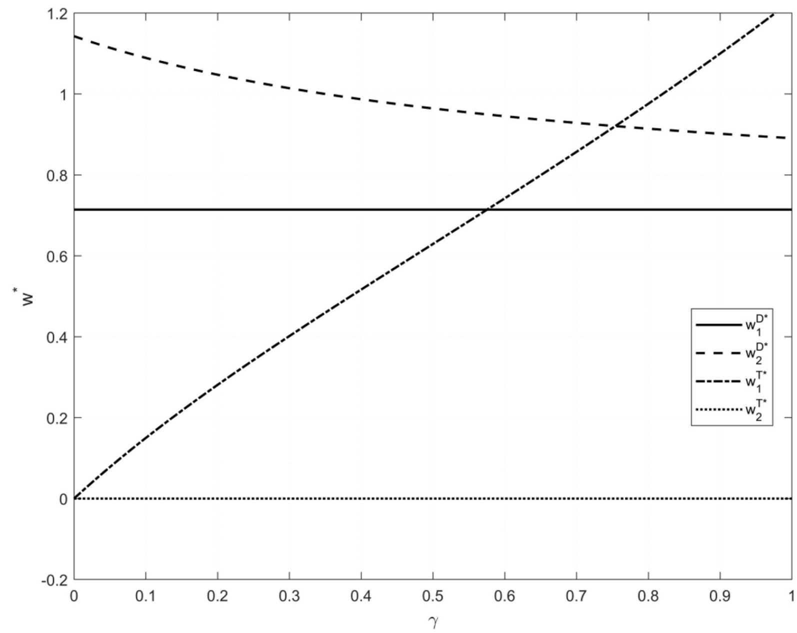

FIGURE 10. Wholesale prices of products before and after coordination.

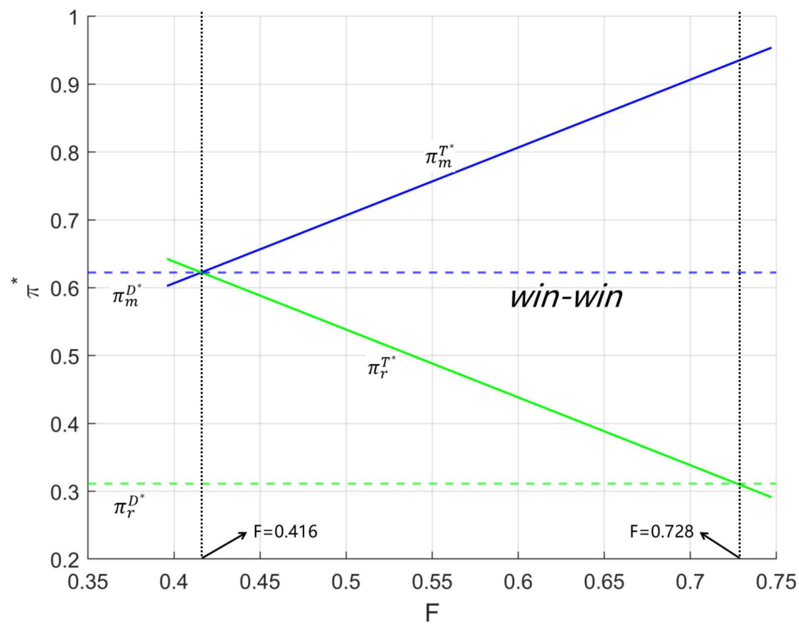

FIGURE 11. Profits of supply chain members before and after coordination.

strategy is recommended to mitigate the negative effects of reference prices, consistent with prior studies [39, 52, 64]. However, when market size grows rapidly and reference price sensitivity is moderate, a price increase in the second stage can still enhance overall profitability – even though reference prices create psychological resistance among consumers. Moderate price hikes can offset the negative impact of fairness perceptions through market volume growth, while accumulating premium space for firms to achieve dual improvements in profitability and demand.

(2) The effects of reference pricing significantly influence both pricing strategies and profit allocation by shaping consumer expectations. Consumers engage in comparisons between current prices and historical ones, establishing a benchmark for perceived fairness. Unlike models that treat RPE as a consumer-only effect [14,67], within a two-stage supply chain context, this dynamic often leads to conflicts between manufacturers and retailers. Manufacturers typically strive to increase wholesale prices for profit maximization; however, retailers concerned with consumer price sensitivity may resist these increases to avert diminished demand. This misalignment can result in inefficient profit distribution and ultimately degrade overall supply chain performance.

(3) Two-part tariff contracts effectively address inefficiencies in decentralized decision-making by combining fixed fees and variable pricing for flexible profit allocation. Previous research has demonstrated the benefits of two-part tariffs [27, 32], but they overlook the RPE, which significantly impacts purchasing decisions in dynamic markets. Our research fills this gap by integrating the RPE into the two-part tariff model. By adjusting fixed fees across sales stages, firms can better align supply chain incentives and mitigate pricing distortions caused by reference price sensitivity. This approach ensures mutual benefits through optimized pricing strategies and enables firms to adapt to changing consumer preferences. In the presence of reference price effects, two-part tariff contracts facilitate more accurate market segmentation and demand forecasting, enhancing overall supply chain performance.

7. Conclusions and future trends

In this paper, we delve into the role of the reference price effect (RPE) in the two-stage pricing strategy of supply chains, especially in the context of consumer price sensitivity and a growing market. The study focuses on how manufacturers and retailers can set prices during the product introduction phase and the subsequent maturity phase to maximize the profits of the entire supply chain.

We construct and solve the Stackelberg game model under decentralized decision-making, both without considering and with considering the RPE. In establishing the demand function that accounts for the RPE, the paper further explores the negative impact of consumers' perception of reference prices under the price increase strategy and the positive impact under the price decrease strategy, followed by a numerical analysis of the model results. A similar research approach is also applied to modeling, solving, and numerical analysis under centralized decision-making. The main conclusions and insights obtained in this paper are as follows:

(1) Research indicates that RPE significantly influences pricing strategies, exhibiting distinct characteristics across various stages of the supply chain and being heavily contingent upon market size. In scenarios where market expansion is relatively constrained, firms are advised to implement a price decrease strategy during the second stage. This approach effectively alleviates the adverse effects of RPE by stimulating consumer demand, particularly among price-sensitive consumers. Furthermore, it diminishes the anchoring effect associated with a high initial price, which could otherwise dissuade potential buyers from making purchases.

(2) Conversely, in cases where substantial market expansion occurs, adopting a price increase strategy may be an advantageous alternative. Although RPE might prompt some consumers to curtail their purchasing activities, the overall increase in market demand enables firms to enhance unit profitability. By strategically raising prices, companies can leverage market expansion opportunities to optimize total revenue generation.

(3) Within decentralized decision-making frameworks, the double marginalization effect becomes increasingly pronounced. Manufacturers and retailers – each striving to maximize their profits – tend to make decisions

independently. This lack of coordination leads to suboptimal performance within the supply chain when compared with centralized decision-making approaches.

(4) To mitigate inefficiencies arising from decentralized decision-making processes, we propose implementing a two-part tariff contract. Under this framework, manufacturers collect fixed fees at both stages while granting retailers increased pricing flexibility. This mechanism serves to alleviate incentive misalignment among members of the supply chain and fosters improved coordination as well as enhanced overall efficiency across varying scenarios of market expansion.

However, this study has its limitations, which open up avenues for future research. Firstly, the assumption of continuous market size growth from the product introduction phase to the maturity phase does not fully reflect real-world situations. Products may enter a decline phase, resulting in a shrinking market size. Future research could consider developing multi-stage supply chain models that incorporate the entire product life cycle, including decline. Secondly, the model assumes that the manufacturer is the leader in the supply chain and captures all residual profits through two-part tariff contracts. In practice, retailers may possess significant bargaining power and could even assume a dominant role. Thus, future studies could explore supply chain coordination mechanisms in retailer-led or dual-leadership structures to optimize overall profitability. Finally, although this study focuses on two-part tariff contracts, other contract types such as revenue-sharing or buyback contracts may also be effective in aligning supply chain interests [33,68]. Future research can conduct comparative analyses of these different contractual mechanisms under various market conditions and consumer behavior patterns. This will provide a more comprehensive theoretical basis and practical guidance for supply chain coordination.

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Appendix A.

Proof of Theorem 1. The Hessian matrix of π_{sc} with respect to p_1 and p_2 is: $H = \begin{bmatrix} -2\beta & 0 \\ 0 & -2\beta \end{bmatrix}$. Obviously, $|H_1| = -2\beta < 0$ and $|H_2| = 4\beta^2 > 0$, so H is negative definite. The profit function is a concave function of p_1 and p_2, with a unique maximum. Solving the system of equations $\frac{\partial \pi_{\text{sc}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\text{sc}}}{\partial p_2} = 0$ yields $p_1^{\text{BC}^*}$ and $p_2^{\text{BC}^*}$. □

Proof of Proposition 1. (i) $p_1^{\text{BC}^*} - p_2^{\text{BC})^*} = -\frac{\delta}{2\beta} < 0$, $D_1^{\text{BC}^*} - D_2^{\text{BC}^*} = -\frac{\delta}{2} < 0$, $\pi_{\text{sc1}}^{\text{BC}^*} < \pi_{\text{sc2}}^{\text{BC}^*} = -\frac{\delta(\delta+2)}{4\beta} < 0$.

(ii) $p_1^{\text{BD}^\star} - p_2^{\text{BD}^\star} = -\frac{3\delta}{4\beta} < 0$, $w_1^{\text{BD}^\star} < w_2^{\text{BD}^\star} = -\frac{\delta}{2\beta} < 0$, $D_1^{\text{BD}^\star} - D_2^{\text{BD}^\star} = -\frac{\delta}{4} < 0$, $\pi_{\text{m1}}^{\text{BD}^\star} - \pi_{\text{m2}}^{\text{BD}^\star} = -\frac{\delta(\delta+2)}{8\beta} < 0$, $\pi_{\text{r1}}^{\text{BD}^\star} - \pi_{\text{r2}}^{\text{BD}^\star} = -\frac{\delta(\delta+2)}{16\beta} < 0$.

(iii) $\pi_{\text{sc1}}^{\text{BC}^*} - \pi_{\text{sc1}}^{\text{BD}^*} = \frac{1}{16\beta} > 0$, $\pi_{\text{sc2}}^{\text{BC}^*} - \pi_{\text{sc2}}^{\text{BD}^*} = \frac{(\delta+1)^2}{16\beta} > 0$, $\pi_{\text{sc}}^{\text{BC}^*} - \pi_{\text{sc}}^{\text{BD}^*} = \frac{\delta^2+2\delta+2}{16\beta} > 0$.

□

Proof of Proposition 2. $\frac{\partial p_1^{C^*}}{\partial \gamma} = \frac{(4\beta^2\delta+4\beta^2+3\gamma^2+\delta\gamma^2+4\beta\gamma)}{(4\beta^2+4\beta\gamma-\gamma^2)^2} > 0$. If $\delta > \frac{-4\beta^2+4\beta\gamma+\gamma^2}{8\beta^2-4\beta\gamma}$, then $\frac{\partial p_2^{D^*}}{\partial \gamma} = \frac{(\gamma^2-4\beta^2-8\beta^2\delta+4\beta\gamma+4\beta\delta\gamma)}{(4\beta^2+4\beta\gamma-\gamma^2)^2} > 0$. If $\delta > \frac{2\gamma}{2\beta-\gamma}$, $\frac{\partial \pi_{\text{sc}}^{C^*}}{\partial \gamma} = \frac{(-4\beta^2\delta^2-4\beta^2\delta+2\beta\delta^2\gamma+4\beta\delta\gamma+4\beta\gamma+\delta\gamma^2+2\gamma^2)}{(4\beta^2+4\beta\gamma-\gamma^2)^2} > 0$. □

Proof of Proposition 3. (i) $p_1^{\text{BC}^*} - p_1^{C^*} = -\frac{\gamma(2\beta+2\beta\delta+\gamma)}{2\beta(4\beta^2+4\beta\gamma-\gamma^2)} < 0$, $p_2^{\text{BC}^*} - p_2^{C^*} = \frac{\delta+1}{2\beta} - \frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$. Let $F(\gamma) = \frac{\delta+1}{2\beta} - \frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2} = \frac{(-\delta)\gamma^2+(4\beta\delta+2\beta)\gamma}{2\beta(4\beta^2+4\beta\gamma-\gamma^2)} = 0$. This quadratic function opens downward, with roots $\gamma_1 = \frac{2\beta(2\delta+1)}{(\delta+1)}$ and $\gamma_2 = 0$. Thus, when $0 < \gamma < \frac{2\beta(2\delta+1)}{(\delta+1)}$, $p_2^{\text{BC}^*} > p_2^{C^*}$. $D_1^{\text{BC}^*} - D_1^{C^*} = \frac{\gamma(2\beta+2\beta\delta+\gamma)}{2(4\beta^2+4\beta\gamma-\gamma^2)} > 0$, $D_2^{\text{BC}^*} - D_2^{C^*} = -\frac{\gamma(2\beta+2\beta\delta+\gamma)}{2(4\beta^2+4\beta\gamma-\gamma^2)} < 0$.

(ii) $\pi_{\text{sc}}^{\text{BC}^*} - \pi_{\text{sc}}^{D^*} = -\frac{\gamma(2\gamma-4\beta\delta-4\beta\delta^2+2\delta\gamma+\delta^2\gamma)}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)}$. Let $F(\gamma) = \frac{(-\delta^2-2\delta)\gamma^2+(4\beta\delta^2+4\beta\delta)\gamma}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)} = 0$. This quadratic function opens downward, with roots $\gamma_1 = \frac{4\beta\delta(\delta+1)}{\delta^2+2\delta+2}$ and $\gamma_2 = 0$. Thus, when $0 < \gamma < \frac{4\beta\delta(\delta+1)}{\delta^2+2\delta+2}$, $\pi_{\text{sc}}^{\text{BC}^*} > \pi_{\text{sc}}^{D^*}$.

□

Proof of Proposition 4. (i) $\frac{\partial w_1^{D^\star}}{\partial \gamma} = 0$, $\frac{\partial w_2^{D^\star}}{\partial \gamma} = -\frac{\delta}{2(\beta+\gamma)^2} < 0$, $\frac{\partial \pi_{\text{M}}^{D^\star}}{\partial \gamma} = \frac{4\beta^2(-1+\delta)\delta+\gamma^2(2+\delta)+2\beta\gamma(2+\delta(2+\delta))}{2(-4\beta^2-4\beta\gamma+\gamma^2)^2}$. Let $F(\delta) = \frac{(2\beta\gamma+4\beta^2)\delta^2+(\gamma^2+4\beta\gamma-4\beta^2)\delta+2\gamma^2+4\beta\gamma}{2(4\beta^2+4\beta\gamma-\gamma^2)^2} = 0$. This quadratic function opens upward, with roots $\delta_1 = -\frac{2\beta+\gamma}{2\beta} < 0$ and $\delta_2 = \frac{2\gamma}{2\beta-\gamma}$. Thus, when $\delta > \frac{2\gamma}{2\beta-\gamma}$, $\frac{\partial \pi_{\text{M}}^{D^\star}}{\partial \gamma} > 0$.

(ii) $\frac{\partial p_1^{D^*}}{\partial\gamma} = \frac{(4\beta^2\delta+4\beta^2+3\gamma^2+\delta\gamma^2+4\beta\gamma)}{2(4\beta^2+4\beta\gamma-\gamma^2)^2} > 0$, $\frac{\partial p_2^{D^*}}{\partial\gamma} = -\frac{(4\beta^4-\gamma^4-6\beta\gamma^3-5\beta^2\gamma^2+4\beta^3\gamma+8\beta^2\delta\gamma^2)}{2(4\beta^3+8\beta^2\gamma+3\beta\gamma^2-\gamma^3)^2}$. Let $F(\delta) = \frac{\gamma\left(\beta(\gamma+11\gamma\delta)+2\beta^2(1+6\delta)-\gamma^2(1+3\delta)\right)}{4\beta((\beta+\gamma)(4\beta^2+4\beta\gamma-\gamma^2))}$ with root $\delta_3 = \frac{(\beta+\gamma)^2(-4\beta^2+4\beta\gamma+\gamma^2)}{8\beta^2\gamma^2-12\beta\gamma^3+\gamma^4}$. Since $4\beta^2+4\beta\gamma-\gamma^2>0$, $\delta_3>0$ when $\delta > \frac{(\beta+\gamma)^2(-4\beta^2+4\beta\gamma+\gamma^2)}{24\beta^4+44\beta^3\gamma+8\beta^2\gamma^2+\gamma^4}$. $\frac{\partial\pi_{\mathrm{R}}^{D^*}}{\partial\gamma} = \frac{(2\beta+\gamma)(2\beta(\delta-1)\delta+\gamma(2+\delta))}{2(-4\beta^2-4\beta\gamma+\gamma^2)^2}$. Let $F(\delta) = \frac{(2\beta+\gamma)(2\beta(\delta-1)\delta+\gamma(2+\delta))}{2(-4\beta^2-4\beta\gamma+\gamma^2)^2} = 0$. This quadratic function opens upward, with roots $\delta_4 = -\frac{2\beta+\gamma}{2\beta} < 0$ and $\delta_5 = \frac{2\gamma}{2\beta-\gamma}$. Thus, when $\delta > \frac{2\gamma}{2\beta-\gamma}$, $\frac{\partial\pi_{\mathrm{R}}^{D^*}}{\partial\gamma} > 0$.

□

Proof of Proposition 5. (i) $p_1^{\mathrm{BD}^*} - p_1^{D^*} = -\frac{\gamma(2\beta+2\beta\delta+\gamma)}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)} < 0$, $p_2^{\mathrm{BD}^*} - p_2^{C^*} = \frac{\gamma(12\beta^2\delta+2\beta^2-\gamma^2-3\delta\gamma^2+\beta\gamma+11\beta\delta\gamma)}{4\beta(4\beta^3+8\beta^2\gamma+3\beta\gamma^2-\gamma^3)}$. Let $F(\delta) = \frac{\gamma(-\gamma^2(1+3\delta)+2\beta^2(1+6\delta)+\beta(\gamma+11\gamma\delta))}{4\beta[(\beta+\gamma)(4\beta^2+4\beta\gamma-\gamma^2)]}$. This quadratic function opens downward, giving the solution $\delta_6 = -\frac{2\beta^2+\beta\gamma-\gamma^2}{12\beta^2+11\beta\gamma-3\gamma^2}$. Thus, $p_2^{\mathrm{BD}^*} > p_2^{D^*}$ when $\delta > -\frac{2\beta^2+\beta\gamma-\gamma^2}{12\beta^2+11\beta\gamma-3\gamma^2}$. $w_1^{\mathrm{BD}^*} - w_1^{D^*} = 0$, $w_2^{\mathrm{BD}^*} - w_2^{D^*} = \frac{\delta\gamma}{2\beta(\beta+\gamma)} > 0$, $D_1^{\mathrm{BC}^*} - D_1^{C^*} = \frac{\gamma(2\beta+2\beta\delta+\gamma)}{4(4\beta^2+4\beta\gamma-\gamma^2)} > 0$, $D_2^{\mathrm{BC}^*} - D_2^{C^*} = -\frac{\gamma(2\beta+2\beta\delta+\gamma)}{4(4\beta^2+4\beta\gamma-\gamma^2)} < 0$.

(ii) $\pi_{\mathrm{sc}}^{\mathrm{BD}^*} - \pi_{\mathrm{sc}}^{D^*} = -\frac{3\gamma(2\gamma-4\beta\delta-4\beta\delta^2+2\delta\gamma+\delta^2\gamma)}{16\beta(4\beta^2+4\beta\gamma-\gamma^2)}$. Let $F(\gamma) = \frac{(-3\delta^2-6\delta)\gamma^2+(12\beta\delta^2+12\beta\delta)\gamma}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)} = 0$. This quadratic function opens downward, with solutions $\gamma_3 = \frac{4\beta\delta(\delta+1)}{(\delta^2+2\delta+2)}$ and $\gamma_4 = 0$. Thus, $\pi_{\mathrm{sc}}^{\mathrm{BD}^*} > \pi_{\mathrm{sc}}^{D^*}$ when $0<\gamma<\frac{4\beta\delta(\delta+1)}{(\delta^2+2\delta+2)}$.

□

Proof of Proposition 6. (i) $p_1^{C^*} - p_2^{C^*} = \frac{2\gamma-2\beta\delta+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$. Let $F(\delta) = \frac{2\gamma-2\beta\delta+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2} = 0$, giving $\delta_7 = \frac{2\gamma}{2\beta-\gamma}$. Since this quadratic function opens downward, $p_1^{C^*} > p_2^{C^*}$ when $0<\delta<\frac{2\gamma}{2\beta-\gamma}$. $D_1^{C^*} - D_2^{C^*} = -\frac{2\beta^2\delta+2\gamma^2+2\beta\gamma+3\beta\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2} < 0$, $\pi_{\mathrm{sc1}}^{C^*} - \pi_{\mathrm{sc2}}^{C^*} = \frac{\left(\gamma^2+\beta(2\beta+\gamma)\delta\right)(2\beta(2+\delta)+\gamma(4+\delta))}{(-4\beta^2-4\beta\gamma+\gamma^2)^2} < 0$.

(ii) $p_1^{D^*} - p_2^{D^*} = \frac{2\gamma^2-6\beta^2\delta+2\delta\gamma^2+2\beta\gamma-5\beta\delta\gamma}{2(4\beta^3+8\beta^2\gamma+3\beta\gamma^2-\gamma^3)}$. Let $F(\delta) = \frac{2\gamma^2-6\beta^2\delta+2\delta\gamma^2+2\beta\gamma-5\beta\delta\gamma}{2(4\beta^3+8\beta^2\gamma+3\beta\gamma^2-\gamma^3)} = 0$. This quadratic function opens downward, giving $\delta_7 = \frac{2\gamma(\beta+\gamma)}{6\beta^2+5\beta\gamma-2\gamma^2}$. Thus, $p_1^{C^*} < p_2^{C^*}$ when $\delta > \frac{2\gamma(\beta+\gamma)}{6\beta^2+5\beta\gamma-2\gamma^2}$. $w_1^{D^*} - w_2^{D^*} = -\frac{\delta}{2(\beta+\gamma)} < 0$, $D_1^{D^*} - D_2^{D^*} = -\frac{2\beta^2\delta+2\gamma^2+2\beta\gamma+3\beta\delta\gamma}{2(4\beta^2+4\beta\gamma-\gamma^2)} < 0$, $\pi_{\mathrm{m1}}^{D^*} - \pi_{\mathrm{m2}}^{D^*} = -\frac{\gamma^2+\beta^2\delta(2+\delta)+\beta(\gamma+2\gamma\delta)}{2\beta(4\beta^2+4\beta\gamma-\gamma^2)} < 0$, $\pi_{\mathrm{r1}}^{D^*} - \pi_{\mathrm{r2}}^{D^*} = -\frac{\left(\gamma^2+\beta(2\beta+\gamma)\delta\right)(2\beta(2+\delta)+\gamma(4+\delta))}{4(-4\beta^2-4\beta\gamma+\gamma^2)^2} < 0$.

(iii) $\pi_{\mathrm{sc1}}^{C^*} - \pi_{\mathrm{sc1}}^{D^*} = \frac{\beta^2(2\beta+\gamma-\gamma\delta)(2\beta+\gamma(5+3\delta))}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)^2}$. Let $F(\delta) = \frac{\beta^2(2\beta+\gamma-\gamma\delta)(2\beta+\gamma(5+3\delta))}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)^2}$. This quadratic function opens downward, with solutions $\delta_8 = \frac{2\beta^2+\beta\gamma-\gamma^2}{\beta\gamma}$ and $\delta_9 = -\frac{2\beta^2+5\beta\gamma+\gamma^2}{3\beta\gamma} < 0$. Thus, $\pi_{\mathrm{sc1}}^{C^*} > \pi_{\mathrm{sc1}}^{D^*}$ when $0<\delta<\frac{2\beta^2+\beta\gamma-\gamma^2}{\beta\gamma}$. $\pi_{\mathrm{sc2}}^{C^*} - \pi_{\mathrm{sc2}}^{D^*} = \frac{\gamma(4\beta^3+\gamma^3+\beta\gamma^2(2+3\delta)+\beta^2\gamma(1+2\delta(2+\delta)))}{4\beta(4\beta^2+4\beta\gamma-\gamma^2)^2} > 0$, $\pi_{\mathrm{sc}}^{C^*} - \pi_{\mathrm{sc}}^{D^*} = \frac{2\beta+2\beta\delta+2\gamma+\beta\delta^2+\delta\gamma}{4(4\beta^2+4\beta\gamma-\gamma^2)} > 0$.

□

Proof of Theorem 5. $\frac{\mathrm{d}^2\pi_{\mathrm{r2}}}{\mathrm{d}p_2^2} = -2\beta-2\gamma < 0$, showing that π_{r2} is a strictly concave function of p_2. From $\frac{\mathrm{d}\pi_{\mathrm{r2}}}{\mathrm{d}p_2} = 0$, the optimal response function for p_2 is: $p_2 = \frac{\delta+\beta w_2+\gamma p_1+\gamma w_2+1}{2\beta+2\gamma}$. The retailer's second-stage profit satisfies $(p_2-w_2)D_2 \geq \pi_{\mathrm{r2}}^{D^*}$. When $F = (p_2-w_2)D_2 - \pi_{\mathrm{r2}}^{D^*}$, the manufacturer extracts all the retailer's second-stage surplus. Substituting p_2 into π_{m2}, the second derivative of π_{m2} with respect to w_2 is: $\frac{\mathrm{d}^2\pi_{\mathrm{m2}}}{\mathrm{d}w_2^2} = -\beta-\gamma < 0$, showing that π_{m2} is a strictly concave function of w_2. From $\frac{\mathrm{d}\pi_{\mathrm{m2}}}{\mathrm{d}w_2} = 0$, the optimal response function for w_2 is: $w_2 = \frac{\left(\frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2} - \frac{\delta+\gamma p_1+1}{2\beta+2\gamma}\right)(2\beta+2\gamma)}{\beta+\gamma}$. Substituting the optimal response functions of p_2 and w_2 into π_{r}, the second derivative of π_{r} with respect to p_1 is: $\frac{\mathrm{d}^2\pi_{\mathrm{r}}}{\mathrm{d}p_1^2} = -2\beta < 0$, so π_{r} is a strictly concave function of p_1. Similarly, from $\frac{\mathrm{d}\pi_{\mathrm{r}}}{\mathrm{d}p_1} = 0$, the optimal response function for p_1 is: $p_1 = \frac{2\beta+3\gamma+\delta\gamma}{4\beta^2+4\beta\gamma-\gamma^2}$. For the retailer to accept the contract, its total profit over two stages must be at least the same as in the decentralized case, *i.e.*, $(p_1-w_1)D_1+(p_2-w_2)D_2 \geq \pi_{\mathrm{r}}^{D^*}$. The manufacturer extracts all the retailer's surplus *via* F, so let $F=(p_1-w_1)D_1+(p_2-w_2)D_2-\pi_{\mathrm{r}}^{D^*}$, yielding F_2^* and F^*.

The second-order derivative of the retailer's profit function in the second period π_{r2} concerning the retail price p_2^T is given by: $\frac{\mathrm{d}^2\pi_{r2}}{\mathrm{d}(p_2^T)^2}=-2\beta-2\gamma<0$. This indicates that π_{r2} is a strictly concave function of p_2^T. Solving the first-order condition $\frac{\mathrm{d}\pi_{r2}}{\mathrm{d}p_2^T}=0$ yields the optimal reaction function for $p_2^T=\frac{\delta+\beta w_2+\gamma p_1+\gamma w_2+1}{2\beta+2\gamma}$. When $p_2^T=p_2^{C^*}$, the supply chain achieves effective coordination. Substituting p_2^T into the manufacturer's profit function π_{m2} and computing the second-order derivative with respect to w_2^T: $\frac{\mathrm{d}^2\pi_{m2}}{\mathrm{d}w_2^2}=-\beta-\gamma<0$ This confirms π_{m2} is a strictly concave function of w_2^T. Solving the first-order condition $\frac{\mathrm{d}\pi_{m2}}{\mathrm{d}w_2^T}=0$ gives the optimal reaction function for $w_2^T=\frac{\left(\frac{2\beta+2\beta\delta+\gamma}{4\beta^2+4\beta\gamma-\gamma^2}-\frac{\delta+\gamma p_1+1}{2\beta+2\gamma}\right)(2\beta+2\gamma)}{\beta+\gamma}$. Substituting the optimal reaction functions of p_2^T and w_2^T into π_r, the second-order derivative with respect to p_1^T is: $\frac{\mathrm{d}^2\pi_r}{\mathrm{d}(p_1^T)^2}=-2\beta<0$. Thus, π_r is strictly concave in p_1^T. Solving $\frac{\mathrm{d}\pi_r}{\mathrm{d}p_1^T}=0$ gives: $p_1^T=\frac{\beta w_1+1}{2\beta}$. When $p_1^T=p_1^{C^*}$, the supply chain coordinates effectively, leading to: $w_1^T=\frac{\gamma(2\beta+2\beta\delta+\gamma)}{\beta(4\beta^2+4\beta\gamma-\gamma^2)}$, $w_2^T=0$. Substituting optimal solutions yields the manufacturer and retailer's optimal profits. To ensure $\pi_m^T>\pi_m^D$ and $\pi_R^T>\pi_R^D$, adjusting fixed fees $\{F_1,F_2\}$ aligns total supply chain profit with centralized decision-making while enhancing both parties' profits. □