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Dynamic Operational Strategies Incorporating Consumer Reference Price Effects and Enterprise Behavior: A Differential Game Approach

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Abstract: The continuous evolution of consumer behavior in the modern era of consumption has prompted enterprises to explore the underlying behavioral factors of consumers and cater to their particular needs. Moreover, developing a rational operational behavior model and responding effectively to the dynamic market environment have become critical concerns for businesses. This study examines the impact of consumer reference price effects and enterprise short-sighted behavior on strategic selection and performance, employing differential game theory to construct a game model between manufacturers and retailers. Utilizing Behrman's continuous dynamic programming theory, analytical solutions for various models are derived, followed by comparative analyses and numerical examples. The research reveals that: (1) manufacturers' behavior patterns are found to be dominant, favoring far-sighted behavior, which not only enhances profits but also enables consumers to access higher quality and cost-effective products; retailers should opt for collaboration with far-sighted manufacturers and exhibit a preference for short-sighted behavior. (2) In terms of overall system profit, the FM model emerges as the optimal combination. (3) When the reference price effect has a small impact on market demand, enterprises can make use of the reference price effect to actively promote marketing and gain profit; as the influence increases, intensifying the degree of influence effectively augments profits.

Keywords: Reference price effect; Short-sighted and far-sighted; Dynamic strategy

1 Introduction

In the ever-changing market environment, enterprises must adopt far-sighted strategies in response to continuous fluctuations. A far-sighted strategy involves anticipating market changes, formulating proactive plans and ensuring that the company adapts to market trends. However, research has shown that due to market complexities, some organizations adopt short-sighted behavior to cope with turbulent market conditions [1]. Short-sighted behavior, as described by Theodore Levitt in his seminal work "Marketing Myopia", refers to a narrow focus on immediate product development and profits while neglecting long-term competitiveness and growth [2, 3]. Conversely, far-sighted behavior encompasses long-term strategy and performance. The choice between short-sighted and far-sighted behavior plays a crucial role in organizational success and has become a popular research topic among scholars.

Apart from price, factors such as product quality, service, and brand goodwill influence consumer purchasing decisions. Chiang et al. [4] found that consumers form expectations about product quality based on previous brand goodwill, purchase service, and promotions. These expectations, or reference quality, affect consumer demand when the perceived quality of a product exceeds the reference level. Similarly, the reference price effect constrains consumer purchasing decisions and determines market demand fluctuations [5]. Therefore, businesses should consider the reference price effect when formulating operational strategies.

This study aims to explore the interplay between enterprise and consumer behaviors, incorporating brand goodwill and reference price effects. Differential game models are constructed to investigate the behaviors and operational decisions of organizations in dynamic environments when their members exhibit different behavioral patterns. The research questions to be addressed are: (1) Which company's behavior pattern plays a dominant role in the supply chain, considering the dual influence of brand goodwill on reference price and market demand? From the perspectives of manufacturers and retailers, which behavior model should organizations prefer to maximize their profits and with

whom should they cooperate? (2) From the consumer's perspective, which behavioral model facilitates the acquisition of better-quality products? (3) Taking into account the total system profit, which combination of behavior patterns results in the highest overall profit?

The contributions of this study are twofold. First, it comprehensively considers the selection of corporate behavior patterns and the influence of consumer behavior factors, examining the formulation of operational strategies under the reference price effect's impact, which has practical implications. Second, previous studies have primarily focused on static corporate behavior pattern selection, with little attention given to the dynamic environment. This study introduces a dynamic equation for brand goodwill and considers the price dependence on brand goodwill, addressing strategy formulation in a dynamic environment, which constitutes the study's innovation.

The remainder of the study is organized as follows: Section 2 presents the literature review, Section 3 introduces the research methodology, Section 4 provides the results and discussion, and Section 5 offers the conclusion and implications of the study.

2 Literature Review

This section delves into the relevant research themes closely related to this study, including the reference price effect, short-sighted and far-sighted behavior, and dynamic operational strategies.

In the realm of reference price effect, Kopalle and Winer [6] developed a dynamic model that incorporated reference price, examining the monopolist's time-varying decisions concerning price and product quality. It was found that when the impact of losses (actual price greater than reference price and product quality lower than expected quality) on demand is equal to or greater than the related gains, the monopolist's optimal strategy involves maintaining constant price and product quality levels. Kalyanaram and Winer [7] empirically generalized reference price, discovering that consumers rely on past brand prices as reference prices when deciding whether to purchase a brand's product. Additionally, consumers demonstrated greater sensitivity to "loss" (actual product price higher than expected reference price) than to "gain". Kopalle et al. [8] investigated the asymmetric reference price effect and dynamic pricing strategies, determining that reference price serves as an anchor level. Consequently, consumer demand for a brand depends not only on the brand price, but also on the perceived loss (brand price higher than reference price) or perceived gain (brand price lower than reference price) at that time. Martín-Herrán et al. [9] analyzed the dual role of price and short-sightedness in marketing channels, asserting that changes in retail prices contribute to establishing an internal reference price. Their findings indicated that short-sighted retailers are agents that overlook the impact of their pricing strategy on the evolution of perceived brand quality and reference prices.

Zhang et al. [10] conducted research on how coordinated supply chains with reference price effects would change due to cooperative advertising. Xu and Liu [11] examined closed-loop supply chains influenced by reference price effects, led by manufacturers, and found that higher reference price coefficients resulted in lower profits for manufacturers and retailers. They also determined that cases without reference price effects outperformed those with reference price effects. Zhang [12] analyzed a joint inventory pricing model with a reference price effect and proved that a reference price-related basic inventory policy is optimal. Urbany et al. [13] investigated the influence of advertisers' price statements on consumers' perceptions and price search behavior, revealing that reasonable reference prices lead to higher estimates of regular prices and perceived offer values for advertisers compared to ads without reference prices. Moreover, exaggerated reference prices hold the same positive impact on perceptions as credible reference prices. Anton et al. [14] constructed a game-theoretical model with two retailers to study the effect of external reference price effect as well as consumer loyalty effect on the operation strategies of two retailers. The findings showed that two retailers will promote equilibrium when their consumer loyalty is more balanced, and the reference price effect reaches a certain strength; otherwise, only one retailer promoting situation will occur. Hu et al. [15] constructed a stylized model considering bilateral reference price effects as a way to verify whether disclosing or hiding member-only discounts generates higher revenue. They compared the revenue gap between information disclosure and hiding strategies for exogenous and endogenous member discounts, finding that for the high-end market, charging higher product prices and membership fees, target customers holding higher negative but lower positive reference price effect platforms should implement an information hiding strategy. Overall, the reference price effect of consumers has generally become a focal point in academia. However, previous studies mainly focused on the impact of reference price effect on enterprise pricing strategies, quality level strategies, and advertising strategies, neglecting the impact of reference price effects when enterprise members exhibit different behavioral patterns from a consumer perspective. This study considers the behavioral factors of the enterprise side and examines the selection of different behavior patterns of enterprises, enriching research in this field.

In the area of research on members' short-sighted and far-sighted behaviors, Liu et al. [16] explored the effects of short-sightedness on product quality, pricing, and performance in the presence of reference quality. They discovered that short-sighted manufacturers have higher product quality, pricing strategies, and cost-effectiveness. However, retailers are not always willing to cooperate with far-sighted manufacturers, and the whole system is highly profitable when both parties adopt short-sighted strategies. Sošić [17] considered a decentralized distribution system model

consisting of n retailers selling the same product and viewed stability from a far-sighted perspective. They found that far-sighted retailers always maximize their allocations by not leaving the grand coalition. Gutierrez and He [18] analyzed the dynamic strategic interactions between manufacturers and retailers in innovative durable products, showing that, in some environments, manufacturers work better with visionary retailers, while in others, they work better with myopic retailers. Dutta et al. [19] studied visionary network formation and demonstrated the existence of a balanced process of network formation. Unfortunately, although the aforementioned literature has examined the short-sighted and far-sighted behavior of members from different perspectives, it lacks studies that consider the behavior of supplychain members with different time horizons, in conjunction with the reference price effect. The present study bridges this gap by exploring the impact of varying time horizons on supply chain members' decision-making processes and overall performance, incorporating the reference price effect.

In the field of dynamic operational strategies, Aviv et al. [20] examined a model in which the manufacturer dynamically determines the retail price and promotional frequency, taking into account the effects of reference price and inventory. Their results indicated that the optimal dynamic pricing strategy consists of periodic promotions, with the regular price and promotional price remaining constant over time. He et al. [21] developed a dynamic pricing model under the effects of reference price and loss aversion, which revealed that the optimal pricing strategy is a combination of dynamic pricing and constant pricing. He et al. [22] proposed a dynamic pricing and inventory management model with reference price effects, finding that a dynamic pricing strategy can outperform a constant pricing strategy. Li et al. [23] investigated the impact of reference price effects on the optimal dynamic pricing and inventory control policies for perishable products. They found that the reference price effect reduces the optimal price and order quantity, while increasing the consumer surplus. The aforementioned research provides valuable insights into dynamic operational strategies under reference price effects. However, they primarily focus on pricing and inventory strategies, with limited attention given to the roles of supply chain members with different time horizons. This study seeks to contribute to this area by considering the impact of various time horizons on the optimal dynamic operational strategies of supply chain members under reference price effects.

In summary, this study addresses gaps in the literature by considering the reference price effect and the varying time horizons of supply chain members. Specifically, it investigates the dynamic operational strategies of manufacturers and retailers, as well as their performance when faced with the complexities of both short-sighted and far-sighted behavior. By doing so, this research aims to enrich the understanding of the relationships between the reference price effect, members' behavioral patterns, and dynamic operational strategies in supply chain management.

3 Problem Description and Model Assumptions

The aim of this study is to analyze a supply chain system consisting of a manufacturer, denoted as M, who determines the quality level $q(t)$ and the wholesale price $w(t)$, and a retailer, denoted as R, who establishes the retail price $p(t)$. This paper incorporates the reference price effect, where the reference price relies on the brand goodwill of the product, which is also influenced by the product quality level. The goodwill and the reference price effect jointly affect market demand. In this paper, a dynamic game model is constructed to investigate the optimal strategies for a manufacturer and a retailer under the influence of the reference price effect when they adopt different combinations of farsighted and short-sighted behavior patterns and the impact on supply chain performance at this time. The relevant hypotheses are provided as follows:

Hypothesis 1: Consumers have an initial judgment on the price of a brand product before purchasing it, leading to a reference price. Referring to the model assumptions from previous literature and combining them with real-life situations, we adopt He et al.'s [22] suggestion that consumers rely on brand goodwill $G(t)$ to judge the quality level before purchasing a product, and that the product quality level and brand goodwill are positively correlated. This paper assumes that consumers' reference price level $R_p(t)$ also relies on brand goodwill $G(t)$ and is positively correlated with goodwill. That is, consumers believe that products with goodwill will have higher prices. Therefore,

$$R_p(t) = \xi\sqrt{G(t)} \tag{1}$$

where, $\xi > 0$ indicates the correlation coefficient between reference price and brand goodwill, and the larger the ξ, the more consumers rely on goodwill in judging the reference price of the product.

Hypothesis 2: The quality level of the product group developed by the manufacturer effectively contributes to the establishment of goodwill [23]. In other words, establishing brand goodwill requires examining the quality level of the product (product efficacy, longevity, hardware facilities, etc.), but brand goodwill is not static. Instead, it changes in a dynamic environment and will gradually diminish as consumers fade away from the product or as other brands from the same industry rise. With the help of Nerlove and Arrow [24], the change in the state variable $G(t)$ is described as

$$\dot{G}(t) = \gamma q(t) - \delta G(t), G(0) = G_0 > 0 \tag{2}$$

where, $q(t)$ represents the product quality level, $\gamma > 0$ is the influence factor of product quality level on brand goodwill, the larger γ indicates the greater influence of quality level on brand goodwill, $\delta > 0$ represents the decay factor or forgetting factor of product brand goodwill, $G_0 > 0$ represents the brand goodwill of the product at the initial moment.

Hypothesis 3: When consumers purchase a product, they pay attention not only to the price but also to the brand goodwill of the product [25]. Additionally, the reference price effect of consumers constitutes an inherent dynamic of the change in market demand. Therefore, the demand function of the market is

$$D(t) = \beta \left(R_p(t) - p(t)\right) + \theta\sqrt{G(t)} \tag{3}$$

where, $R_p(t)$ is the reference price, $p(t)$ is the product price, $\beta\left[R_p(t) - p(t)\right]$ represents the reference price effect, and $\beta > 0$ represents the effect of the reference price effect on market demand. When $R_p(t) - p(t) \geq 0$, market demand increases; when $R_p(t) - p(t) < 0$, market demand decreases. Moreover, brand goodwill also affects market demand; good brand goodwill will have a positive effect on demand, and bad brand goodwill will suppress market demand. $\theta > 0$ indicates the coefficient of influence of goodwill on market demand. It can be seen that a higher reference price can effectively drive market demand, and establishing and maintaining goodwill is a long-term solution to ensure good market demand. Furthermore, from Eq. (1) and Eq. (3), we can derive

$$D(t) = \Phi\sqrt{G(t)} - \beta p(t) \tag{4}$$

where, $\Phi = \theta + \beta\xi$.

Hypothesis 4: The manufacturer's quality level is positively related to the cost it incurs. Drawing on the common cost convexity assumption [26], the quality input cost at time t is $\frac{1}{2}kq^2(t)$, and $k > 0$ and is the impact factor of quality cost.

Hypothesis 5: The manufacturer and the retailer have an infinite planning horizon, aim to maximize utility, and have the same discount rate of r. For the visionary actor, when formulating each strategy of the firm, it is essential to consider the impact of current decisions on future benefits in addition to the impact of current decisions on present benefits. Thus, the objective generalizations of the visionary manufacturer and the visionary retailer are

$$V_M^F[w(t), q(t); p(t)] = \int_0^{+\infty} e^{-rt}\left\{w(t)\left[\Phi\sqrt{G(t)} - \beta p(t)\right] - \frac{1}{2}kq^2(t)\right\}\mathrm{d}t \tag{5}$$

$$V_R^F[p(t); w(t), q(t)] = \int_0^{+\infty} e^{-rt}\left\{\left[p(t) - w(t)\right]\left[\Phi\sqrt{G(t)} - \beta p(t)\right]\right\}\mathrm{d}t \tag{6}$$

The above formula shows the target functional of manufacturers and retailers with foresight behavior when the planning period is infinite. For short-sighted actors, when making decisions, they only consider current interests and do not consider the impact of decisions on future interests. Therefore, the target functionals for short-sighted manufacturers and short-sighted retailers are

$$V_M^M[w(t), q(t); p(t)] = w(t)\left[\Phi\sqrt{G(t)} - \beta p(t)\right] - \frac{1}{2}kq^2(t) \tag{7}$$

$$V_R^M[p(t); w(t), q(t)] = \left[p(t) - w(t)\right]\left[\Phi\sqrt{G(t)} - \beta p(t)\right] \tag{8}$$

The above objective generalization shows that (5) and (6) target the discounted value of the entire infinite planning period and portray the decisions of the manufacturer and retailer with visionary actions; (7) and (8) target the profit at the present moment and portray the short-sighted behavior of both parties. The manufacturer and the retailer independently choose their behavioral strategies and both conform to the Stackelberg differential game, which can be summarized as

$$\begin{aligned} &\max_{w(\cdot)} V_M^i\left[w(t), q(t); p(t)\right] \\ &\text{s.t.} \begin{cases} \max_{p(\cdot), s(\cdot)} V_R^j\left[p(t); w(t), q(t)\right] \\ \dot{G}(t) = \gamma q(t) - \delta G(t), G(0) = G_0 > 0 \end{cases} \end{aligned} \tag{9}$$

Among them, $i = \{F, M\}$ represents the different situations of manufacturer foresight F and shortsighted M, while $j = \{F, M\}$ represents the different situations of retailer foresight F and shortsighted M.

4 Model Analysis

Based on the previously stated assumptions, the Stackelberg dynamic equilibrium strategies are solved for firm members under two distinctive behavioral pattern combinations: the visionary manufacturer and short-sighted retailer (FM), and the short-sighted manufacturer and long-sighted retailer (MF), respectively. Operational and marketing strategies of the firm members under varying conditions are analyzed, with the goal of uncovering the transformations brought to the firm by these differing behaviors through the process of comparative static analysis. In the following context, the superscripts FM, MF signify the two different combinations of behavioral patterns, and the subscripts M, R symbolize the green suppliers and green retailers, respectively.

4.1 Visionary Manufacturers and Short-Sighted Retailers (FM)

Proposition 1 In the FM mode, the Stackelberg differential game is

$$J_M^F = \max_{w(\cdot),q(\cdot)} \int_0^{+\infty} e^{-rt} \left\{ w(t) \left[\Phi\sqrt{G(t)} - \beta p(t) \right] - \frac{1}{2} k q^2(t) \right\} \mathrm{d}t$$
$$\text{s.t.} \begin{cases} \dot{G}(t) = \gamma q(t) - \delta G(t), G(0) = G_0 \\ J_R^M = \max_{w(\cdot),q())} \{ [p(t) - w(t)] \left[\Phi\sqrt{G(t)} - \beta p(t) \right] \} \end{cases}$$

According to Stackelberg differential games, reverse induction is used for analysis, which is omitted here to save space. From this, it can be concluded that:

(1) The strategies are

$$w^{FM} = \frac{\Phi\sqrt{G^{FM}}}{2\beta}; q^{FM} = \frac{\gamma\Phi^2}{8\beta k(\delta + r)}; \quad p^{FM} = \frac{3\Phi\sqrt{G^{FM}}}{4\beta}.$$

(2) The time evolution paths of G^{FM} and R_p^{FM} are respectively

$$G^{FM} = \frac{\gamma^2\Phi^2}{8\beta k\delta(\delta + r)} + e^{-\delta t} \left(G_0 - \frac{\gamma^2\Phi^2}{8\beta k\delta(\delta + r)} \right); R_p^{FM} = \xi\sqrt{G^{FM}}.$$

(3) The profits of M and R are respectively

$$V_M^{FM} = \frac{\Phi^2}{8\beta(\delta + r)} G^{FM} + \frac{\Phi^4\gamma^2}{128kr\beta^2(\delta + r)^2}; \quad V_R^{FM} = \frac{\Phi^2}{16\beta r} G^{FM}.$$

(4) Total system profit

$$V^{FM} = \left(\frac{\Phi^2}{8\beta(\delta + r)} + \frac{\Phi^2}{16\beta r} \right) G^{FM} + \frac{\Phi^4\gamma^2}{128kr\beta^2(\delta + r)^2}.$$

Property 1 When manufacturers adopt a long-term perspective and retailers are focused on the short-term, the results of sensitivity analysis for critical exogenous variables can be derived from Proposition 1 (as show in Table 1).

Table 1. Sensitivity analysis of key exogenous variables under FM model

	G^{FM}	ξ	θ	γ	β	δ	k
w^{FM}	↗	↗	↗	↗	↘	↘	↘
q^{FM}	×	↗	↗	↗	↘	↘	↘
p^{FM}	↗	↗	↗	↗	↘	↘	↘
R^{FM}	↗	↗	↗	↗	↘	↘	↘
V_M^{FM}	↗	↗	↗	↗	*	↘	↘
V_R^{FM}	↗	↗	↗	↗	*	↘	↘

Note: ↗ stands for positive ratio, ↘ stands for negative ratio, × stands for irrelevant, and * indicates the relationship with exogenous variables subject to the circumstances

Proof: The partial derivative is calculated for the key parameters in the strategy. A result greater than 0 is indicative of proportionality; a result less than 0 denotes inverse proportionality. The absence of the key parameter in the strategy implies irrelevance. If the result is not easily classified as either positive or negative, the conclusion is that the relationship depends on the specific situation.

According to Proposition 1, when a long-term perspective is held by the manufacturer and a short-term perspective is taken by the retailer, the impacts of decisions on both immediate and long-term interests are considered by the

manufacturer, while only immediate interests are taken into account by the retailer, with long-term implications being overlooked. Although the manufacturer's decision is influenced by the strategy of the short-sighted retailer, not each decision of the manufacturer is significantly impacted.

Property 1 demonstrates that: (1) Profits for both parties are increased when manufacturers and retailers are driven to raise their products' wholesale and retail prices, respectively, as goodwill rises. (2) As the correlation between "reference price and brand goodwill" increases, or in other words, as consumers rely more on brand goodwill when pricing a product, operational strategies are encouraged to be enhanced by manufacturers (including product quality and wholesale prices), and retail prices are correspondingly increased by retailers, resulting in higher profits for both parties. (3) An increase in the influence of goodwill on market demand, which means market demand is effectively stimulated by goodwill, and the rise in market demand indicates an increase in product sales, drives manufacturers and retailers to refine their strategies. (4) A stronger influence of product quality on the evolution of brand goodwill increases the incentive for both companies to refine their strategies. (5) A larger reference price effect on market demand discourages investment in quality levels by manufacturers, prompting them to lower wholesale prices, and retail prices are consequently reduced by retailers; the influence of the reference price effect on corporate profits will be confirmed by forthcoming numerical examples.

4.2 Short-Sighted Manufacturers and Visionary Retailers (MF)

Proposition 2 In the MF mode, the Stackelberg differential game is

$$
\begin{aligned}
&J_M^M = \max_{w(\cdot)q(\cdot)} \left\{ w(t) \left[\Phi \sqrt{G(t)} - \beta p(t) \right] - \frac{1}{2} k q^2(t) \right\} \\
&J_R^F = \max_{p(\cdot)} \int_0^{+\infty} e^{-rt} \{ [p(t) - w(t)] \left[\Phi \sqrt{G(t)} - \beta p(t) \right] \} \mathrm{d}t \\
&\text{s.t. } \dot{G}(t) = \gamma q(t) - \delta G(t), G(0) = G_0
\end{aligned}
$$

According to the principles of Stackelberg differential games and employing reverse induction for analysis, we derive the following conclusions:

(1) The strategies are

$$
w^{MF} = \frac{\Phi \sqrt{G^{MF}}}{2\beta}; q^{MF} = 0; p^{MF} = \frac{3\Phi \sqrt{G^{MF}}}{4\beta}.
$$

(2) The time evolution paths of G^{MF} and R_p^{MF} are respectively

$$
G^{MF} = G_0 e^{-\delta t}; \quad R_p^{MF} = \xi \sqrt{G^{MF}}.
$$

(3) The profits of M and R are respectively

$$
V_M^{MF} = \frac{\Phi^2}{8\beta r} G^{MF}; \quad V_R^{MF} = \frac{\Phi^2}{16\beta(\delta + r)} G^{MF}.
$$

(4) Total system profit

$$
V^{MF} = \left(\frac{\Phi^2}{8\beta r} + \frac{\Phi^2}{16\beta(\delta + r)} \right) G^{MF}.
$$

Property 2 When manufacturers are short-sighted and retailers are far-sighted, the sensitivity analysis results of key exogenous variables can be derived from Proposition 2 (as show in Table 2).

Proof: The partial derivative of key parameters in the strategy is computed. If the outcome is greater than 0, it suggests a proportional relationship; if the result is less than 0, it also suggests a proportional relationship. If the key parameter does not feature in the strategy, it implies irrelevance. If the outcome's sign is ambiguous, the implications are situation-dependent.

Proposition 2 and Property 2 reveal that: (1) At this juncture, the manufacturer prioritizes immediate benefits and neglects long-term considerations, whereas the retailer takes a long-term view. As a result, the manufacturer forsakes investments in quality level, meaning quality level remains unaffected by each exogenous variable. Further, the quality level's influence on brand goodwill and the cost coefficient of quality level do not impact the strategy or profits of any party. (2) When the manufacturer is short-sighted, profit fluctuation is greater than when the manufacturer is far-sighted. Even though the retailer is far-sighted at this time, it is influenced by the manufacturer's behavior, resulting in more considerable profit changes. This underscores the dominant role the manufacturer's behavior pattern plays in the supply chain. (3) In this context, brand goodwill is negatively impacted only by the decay factor, therefore the reference price is unaffected by any variable, other than goodwill, the influence factor of goodwill on the reference price, and the decay factor of goodwill.

Table 2. Sensitivity analysis of key exogenous variables under MF model

	G^{MF}	ξ	θ	γ	β	δ	k
w^{MF}	↗	↗	↗	×	↘	↘	×
q^{MF}	×	×	×	×	×	×	×
p^{MF}	↗	↗	↗	×	↘	↘	×
R^{MF}	↗	↗	×	×	×	↘	×
V_M^{MF}	↗	↗	↗	×	*	↘	×
V_R^{MF}	↗	↗	↗	×	*	↘	×

Note: ↗ stands for positive ratio, ↘ stands for negative ratio, × stands for irrelevant, and * indicates the relationship with exogenous variables subject to the circumstances

5 Contrast Analysis

This section undertakes a contrast analysis to explore the strategies of members under two distinct behavioral patterns, calculating steady-state solutions grounded on previous theories and comparing the magnitudes of the relationships.

Proposition 3 states that the relationship in the steady-state of the reference price under the two behavioral patterns $R_\infty^{FF} > R_\infty^{MM}$ is given. This proposition illustrates that a manufacturer's visionary behavior results in increased brand goodwill and consequently higher reference prices. It's clear that the retailer's behavior pattern does not significantly alter product brand goodwill, whereas the manufacturer's behavior pattern plays a critical role.

Proposition 4 determines the relationship between the various steady-state strategies of the manufacturer and retailer $w_\infty^{FM} > w_\infty^{MF}, q_\infty^{FM} > q_\infty^{MF}, p_\infty^{FM} > p_\infty^{MF}$. This proposition elucidates that the manufacturer's visionary behavior has the capacity to enhance the level of each strategy, bolster supply chain operational efficiency, and improve performance, while also intensifying the double marginal effect.

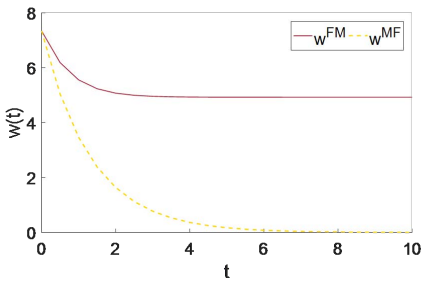
Proposition 5 states that under the two behavioral modes, the steady-state relationship of profit $V_{M\infty}^{FM} > V_{M\infty}^{MF}, \quad V_{R\infty}^{FM} > V_{R\infty}^{MF}$ is described. This proposition shows that when a manufacturer is farsighted, the profit exceeds that when the manufacturer is short-sighted. Hence, suppliers should factor in changes in profitability in the present and the long-term profitability post-decision when devising strategies, and act in a visionary manner to fully leverage all advantageous resources to invest in quality and establish a corporate objective of high quality and high reputation products. However, for retailers, exhibiting short-sighted behavior and collaborating with visionary manufacturers is more profitable than collaborating with short-sighted manufacturers. This suggests that the retailer's strategy should focus not on the behavior exhibited, but on the behavioral pattern of the supplier.

6 Numerical Calculation Example

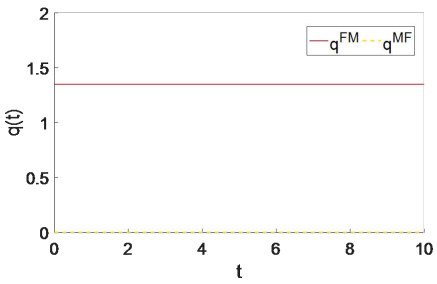
This section serves to further validate previous conclusions through numerical examples, grounded in specific contexts, and analyzes the influence of key parameters ξ and β on both business strategy and profitability. The parameter settings used in these examples are as follows: $\beta = 1, \xi = 2, r = 0.5, \theta = 4, k = 5, \delta = 1.5$.

6.1 Time Trajectories: Strategies & Corporate Profits

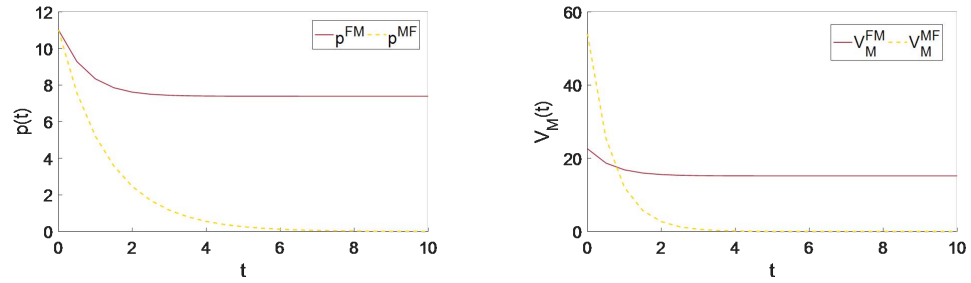
As depicted in Figure 1, both strategic approaches employed by members and firm profits are globally stable over time, a result that aligns with findings previously presented. Significantly, it is observed that overall strategy and profits are elevated when the manufacturer demonstrates farsightedness and the retailer shortsightedness, as compared to the scenario where the manufacturer is shortsighted and the retailer farsighted. This serves to underscore the dominant role the manufacturer plays within the supply chain. Manufacturers exhibit a preference for farsighted behavior, while retailers strategically prioritize partner choice over behavior model selection.



(a) Wholesale price strategy

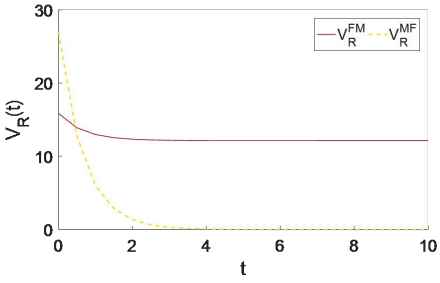


(b) Quality level strategy

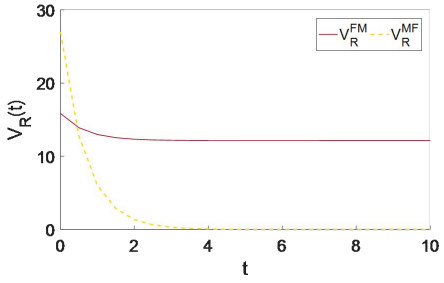


(c) Retail pricing strategy

(d) Manufacturer profit



(e) Retailer profit

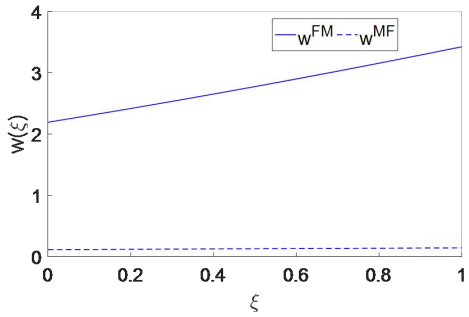


(f) Total profit

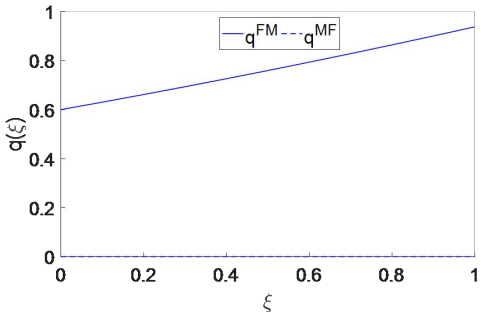
Figure 1. Time trajectory of each strategy and corporate profit under the two behavioral models

6.2 Correlation: Reference Price & Brand Goodwill

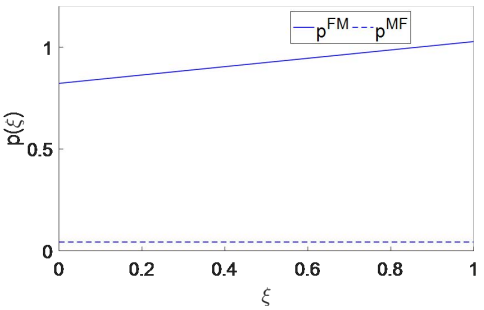
The interdependence of reference price on brand goodwill, given its significant influence on supply chain performance, warrants close examination. The relationship between each decision and ξ is observed after reaching a steady state. Figure 2 presents the trajectory of each member's strategy and supply chain performance as ξ changes from 0 to 1.



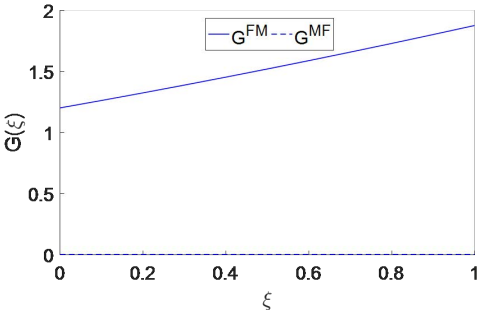
(a) Wholesale price strategy



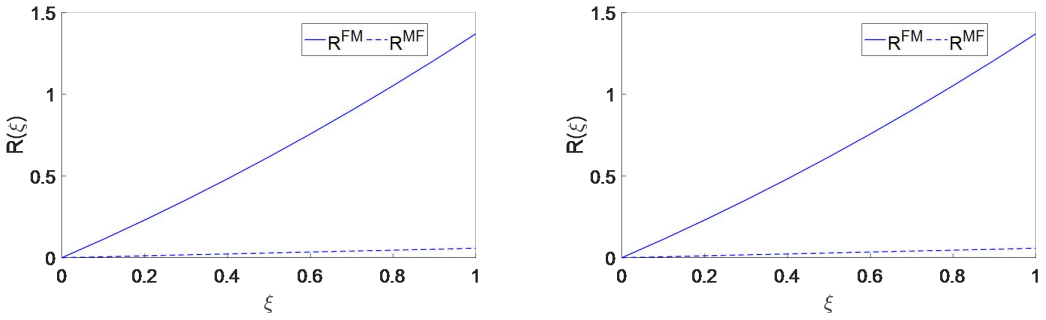
(b) Quality level strategy



(c) Retail pricing strategy

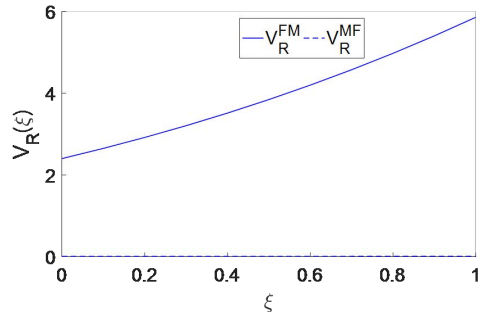


(d) Brand Goodwill

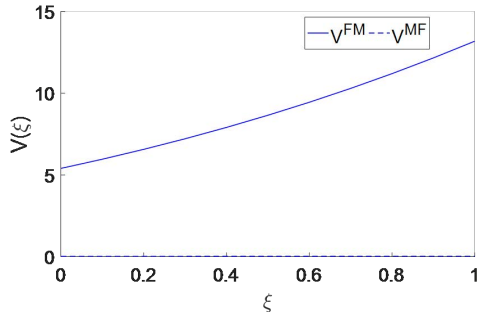


(e) Reference Price

(f) Manufacturer profit



(g) Retailer profit



(h) Total profit

Figure 2. The impact of AAA on strategy and performance under different models of "reference price-brand reputation" correlation

Figure 2 illustrates that, in a steady-state scenario, when the manufacturer is farsighted, the strategies, the manufacturer's profits, the retailer's profits, and total profit increase in line with a rise in consumer reliance on brand goodwill for reference price estimation. In contrast, when the manufacturer is shortsighted, all strategies and profits, with the exception of the reference price, are unaffected by the impact factor. These outcomes reaffirm the importance of brand goodwill within the context of the reference price effect and the dominant role the manufacturer assumes within the supply chain.

7 Conclusion

This study considers the implications of a discrepancy between consumer price expectations and the actual price of a product pre-purchase, also known as the reference price effect. The dual influence of brand goodwill on both the reference price and market demand is highlighted. Furthermore, the study delves into the role of the reference price effect on corporate strategies and profits, particularly when firms exhibit differing behavioral patterns. Two models, predicated on differential game theory, are constructed: the manufacturer-farsighted retailer-shortsighted (FM) and the manufacturer-shortsighted retailer-farsighted (MF). These models facilitate an analysis of the evolution path of brand goodwill, corporate strategies, and profits under the respective behavioral models, accompanied by sensitivity analysis of vital exogenous variables. Validation of prior propositions and deductions is achieved through numerical examples.

The findings can be summarized as follows:

(1) With the inclusion of consumer reference price effects, supplier behavior patterns emerge as pivotal in a supply chain environment, given that brand goodwill simultaneously influences reference price and market demand. Suppliers, opting for a visionary role, drive the development of supply chain strategies effectively. This is manifested in higher quality wholesale products and increased selling prices, fostering higher goodwill and yielding greater profits for themselves and downstream entities. Retailers strategically collaborate with visionary manufacturers, thereby fostering mutually beneficial outcomes.

(2) From a consumer perspective, visionary manufacturers invest more in product quality, leading to elevated wholesale and, consequently, retail prices. However, consumers benefit from higher quality products and superior cost-effectiveness, thus preferring manufacturers with visionary behavior.

(3) Taking into account the aggregate profit of the supply chain system, the MFRS model is determined as the optimal model combination, yielding the highest total profit for the supply chain.

To conclude, under the influence of the reference price effect, manufacturers, the leaders of the supply chain, should maximize their leadership advantage, opting for visionary behavior. They should deliver superior quality and cost-effective products, give due emphasis to brand goodwill, and consider the impact of the reference price effect. This approach is likely to drive corporate and societal development, enhance profits for themselves and downstream retailers, and improve supply chain performance. Retailers, on the other hand, should strategically partner with visionary manufacturers to optimize supply chain performance.

This study, while comprehensive, does have certain limitations. It primarily considers consumer reference price effect factors. However, in reality, consumer reference quality effects also exist, influencing both market demand and corporate performance. Future research should aim to incorporate this factor.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] F. X. Lu, G. W. Liu, J. X. Zhang, and W. S. Tang, "Benefits of partial myopia in a durable product supply chain considering pricing and advertising," *J. Oper. Res. Soc.*, vol. 67, no. 10, pp. 1309–1324, 2016. https://doi.org/10.1057/jors.2016.27

[2] M. Friedman, *A Program for Monetary Stability*. Fordham University Press: New York, 1959.

[3] Y. Liu, J. Zhang, S. Zhang, and G. Liu, "Prisoner's dilemma on behavioral choices in the presence of sticky prices: Farsightedness vs. myopia," *Int. J. Prod. Econ.*, vol. 191, pp. 128–142, 2017. https://doi.org/10.1016/j.ijpe.2017.04.011

[4] W. Y. K. Chiang, D. Chhajed, and J. D. Hess, "Direct marketing, indirect profits: A strategic analysis of dual-channel supply-chain design," *Mgmt. Sci.*, vol. 49, no. 1, pp. 1–20, 2003. https://doi.org/10.1287/mnsc.49.1.1.12749

[5] J. M. Lattin and R. E. Bucklin, "Reference effects of price and promotion on brand choice behavior," *J. Mark. Res.*, vol. 26, no. 3, pp. 299–310, 1989. https://doi.org/10.1177/002224378902600304

[6] P. K. Kopalle and R. S. Winer, "A dynamic model of reference price and expected quality," *Mark. Lett.*, vol. 7, no. 1, pp. 41–52, 1996. https://doi.org/10.1007/bf00557310

[7] G. Kalyanaram and R. S. Winer, "Empirical generalizations from reference price research," *Mgmt. Sci.*, vol. 14, no. 3_supplement, pp. 161–169, 1995. https://doi.org/10.1287/mksc.14.3.g161

[8] P. K. Kopalle, A. G. Rao, and J. L. Assunção, "Asymmetric reference price effects and dynamic pricing policies," *Mgmt. Sci.*, vol. 15, no. 1, pp. 60–85, 1996. https://doi.org/10.1287/mksc.15.1.60

[9] G. Martín-Herrán, S. Taboubi, and G. Zaccour, "Dual role of price and myopia in a marketing channel," *Eur. J. Oper. Res.*, vol. 219, no. 2, pp. 284–295, 2012. https://doi.org/10.1016/j.ejor.2011.12.015

[10] J. Zhang, Q. Gou, L. Liang, and Z. Huang, "Supply chain coordination through cooperative advertising with reference price effect," *Omega*, vol. 41, no. 2, pp. 345–353, 2013. https://doi.org/10.1016/j.omega.2012.03.009

[11] J. Xu and N. Liu, "Research on closed loop supply chain with reference price effect," *J. Intell. Manuf.*, vol. 28, no. 1, pp. 51–64, 2014. https://doi.org/10.1007/s10845-014-0961-0

[12] Y. Zhang, "Essays on robust optimization, integrated inventory and pricing, and reference price effect," Doctoral Dissertation, University of Illinois at Urbana-Champaign, USA, 2010.

[13] J. E. Urbany, W. O. Bearden, and D. C. Weilbaker, "The effect of plausible and exaggerated reference prices on consumer perceptions and price search," *J. Consum. Res.*, vol. 15, no. 1, pp. 95–110, 1988. https://doi.org/10.1086/209148

[14] R. Anton, R. Y. Chenavaz, and C. Paraschiv, "Dynamic pricing, reference price, and price-quality relationship," *J. Econ. Dyn. Control*, vol. 146, p. 104586, 2023. https://doi.org/10.1016/j.jedc.2022.104586

[15] L. Hu, H. L. Ma, L. Wang, and Y. Liu, "Hiding or disclosing? Information discrimination in member-only discounts," *Transp. Res. E-Cem*, vol. 171, p. 103026, 2023. https://doi.org/10.1016/j.tre.2023.103026

[16] G. Liu, S. P. Sethi, and J. Zhang, "Myopic vs. far-sighted behaviours in a revenue-sharing supply chain with reference quality effects," *Int J. Prod. Res.*, vol. 54, no. 5, pp. 1334–1357, 2015. https://doi.org/10.1080/00207543.2015.1068962

[17] G. Sošić, "Transshipment of inventories among retailers: Myopic vs. farsighted stability," *Mgmt. Sci.*, vol. 52, no. 10, pp. 1493–1508, 2006. https://doi.org/10.1287/mnsc.1060.0558

[18] G. J. Gutierrez and X. He, "Life-cycle channel coordination issues in launching an innovative durable product," *Prod. Oper. Manag.*, vol. 20, no. 2, pp. 268–279, 2010. https://doi.org/10.1111/j.1937-5956.2010.01197.x

[19] B. Dutta, S. Ghosal, and D. Ray, "Farsighted network formation," *J. Econ. Theory.*, vol. 122, no. 2, pp. 143–164, 2005. https://doi.org/10.1016/j.jet.2004.05.001

[20] X. He, G. Gutierrez, and S. P. Sethi, "A review of stackelberg differential game models in supply chain management," In 2007 International Conference on Service Systems and Service Management, Chengdu, China, June 9–11, 2007. https://doi.org/10.1109/ICSSSM.2007.4280080

[21] Y. He, J. Zhang, Q. Gou, and G. Bi, "Supply chain decisions with reference quality effect under the O_2O environment," *Ann. Oper. Res.*, vol. 268, no. 1-2, pp. 273–292, 2017. https://doi.org/10.1007/s10479-016-2224-2

[22] Y. He, Q. Xu, B. Xu, and P. Wu, "Supply chain coordination in quality improvement with reference effects," *J. Oper. Res. Soc.*, vol. 67, no. 9, pp. 1158–1168, 2016. https://doi.org/10.1057/jors.2016.10

[23] A. Nair and R. Narasimhan, "Dynamics of competing with quality-and advertising-based goodwill," *Eur. J. Oper. Res.*, vol. 175, no. 1, pp. 462–474, 2006. https://doi.org/10.1016/j.ejor.2005.05.015

[24] M. Nerlove and K. J. Arrow, "Optimal advertising policy under dynamic conditions," *Economica*, vol. 29, no. 144, pp. 129–142, 1962. https://doi.org/10.2307/2551549

[25] B. Dan, S. Zhang, and M. Zhou, "Strategies for warranty service in a dual-channel supply chain with value-added service competition," *Int J. Prod. Res.*, vol. 56, no. 17, pp. 5677–5699, 2017. https://doi.org/10.1080/00207543.2017.1377355

[26] J. P. Caulkins, G. Feichtinger, D. Grass, R. F. Hartl, P. M. Kort, and A. Seidl, "Interaction of pricing, advertising and experience quality: A dynamic analysis," *Eur. J. Oper. Res.*, vol. 256, no. 3, pp. 877–885, 2017. https://doi.org/10.1016/j.ejor.2016.06.056