Research on Investment Strategy of Farsighted Manufacturer under Competitive Environment

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Abstract. Under the competitive environment, the investment strategy of enterprises has an important impact on the profits of supply chain members and social welfare. Aiming at the problem of investment strategy selection of farsighted manufacturer, the technological innovation strategy model and upward invasion strategy model are constructed respectively, and the influences of market competition, innovation efficiency and invasion cost on the investment strategy selection of the farsighted manufacturer and social welfare are discussed. The results show that both investment strategies can intensify market competition, reduce product price and weaken the intensity of product substitution affecting market competition, and the farsighted manufacturer is more aggressive in pricing. Due to the comprehensive influence of product substitutability, innovation cost coefficient and invasion cost, both investment strategies have their own advantages for the farsighted manufacturer. However, the fiercer the market competition, the more necessary it is for the farsighted manufacturer to implement the upward invasion strategy, and with the increase of innovation cost coefficient, the area where social welfare has an advantage under upward invasion strategy gradual expands.

Keywords: competitive environment; farsighted manufacturer; technical innovation strategy; upward invasion strategy; social welfare

1 Introduction

With the rapid development of science and technology and the increasingly fierce market competition, the farsighted behavior of enterprises has become an important guarantee for enterprises to enhance their competitiveness, adapt to market changes and achieve long-term development. Farsighted enterprises can pay attention to the long-term development trend of the industry and gain insight into the influence of new technologies, new markets and other factors on the industry in advance, so as to adapt to the trend in decision-making and avoid being eliminated by the market because of short sightedness. Under the current trend of green development, some farsighted enterprises continue to invest in technological innovation, and strive to enhance their core competitiveness through innovation, so that enterprises can maintain their advantages in the long-term market competition. For example, Huawei insists on technological

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innovation and successfully launched its self-developed HarmonyOS operating system to invade upstream suppliers in 2019, thus replacing the Android operating system. However, in order to disperse market risks and break through the competitive boundary, some farsighted enterprises may break the original industry barriers and invade new markets. For example, Xiaomi Group invaded the new energy vehicle market through cooperation and self-building, and the advantages of intelligent hardware and Internet provided strong support for Xiaomi's development in the new energy vehicle market. Then, faced with the complicated and changeable market competition environment, how small and medium-sized enterprises should choose the optimal investment strategy so as to maximize their own profits is a key issue facing enterprises, and it is also the main problem studied in this paper.

Technological innovation is the key driver for a company's sustainable development. Through the transformation of production technology and technological innovation, it not only brings cost effect to manufacturing enterprises, but also promotes their technological progress [1]. For example, installing variable valves to improve fuel economy in automobiles is an example of promoting technological progress through the transformation of production technology. The saving of production cost per unit product brought by technological innovation is conducive to the improvement of profits of supply chain members [2], and sharing green investment costs between upstream and downstream of supply chain can bring more benefits to supply chain members [3]. Wu et al. [4] studied the situation of retailers' investment in manufacturers' green technology research and development. The results show that in order to encourage manufacturer to improve the green level of product, retailer would launch green subsidy strategies, but retailers' concern for fairness could weak manufacturers' motivation to improve the green level of products. With the increasingly complex market environment and fierce competition among enterprises, only when enterprises in the same supply chain cooperate with each other and fully share information can they gain greater competitive advantage and generate more substantial benefits [5].

In recent years, more and more manufacturing enterprises have opened online direct sales channels to invade downstream retailers, such as Haier, Cisco and Three Squirrels. Scholars have conducted in-depth research on channel invasion from different perspectives [6-9]. For example, Duan et al. [6] have studied the influence of manufacturer's direct selling invasion on supply chain from the perspective of demand information sharing. Huang et al. [8] discussed the situation of supplier direct selling invading retailers from the perspective of revenue sharing, and found that when the service cost of retailers is high, supplier invasion can benefit itself. With the gradual improvement of the market system, the market access threshold of many industries has been greatly reduced, and it is more common for foreign enterprises to break through the industrial barriers through technological innovation. Although incumbent manufacturers cannot prevent new entrants from entering the market when the entry cost is low [10], they can reduce product production costs through technological investments, thereby making it more difficult for new manufacturers to enter the market [11]. Cao et al. [12] found that when the product quality difference is large, foreign manufacturers would choose direct sales invasion, while when the product quality difference is small, foreign manufacturers would choose another retailer to sell on their behalf.

As can be seen from the above literature, scholars have conducted in-depth research on technological innovation and market invasion respectively, but few literature studies have considered both. Technology innovation strategy can create technical barriers, reduce costs, and generate differentiated value. Market entry strategy enable rapid penetration into target markets and the acquisition of a larger share of the market. In actual operations, some companies often face the choice between technological innovation strategy and upward expansion strategy. In view of this, in the competitive environment, aiming at the problem of investment strategy selection of farsighted manufacturer, this paper constructs technological innovation strategy and upward invasion strategy, explores the influence of factors such as product substitution, innovation efficiency and invasion cost on investment strategy selection of farsighted manufacturer and social welfare, and compares and analyzes the intensity of market competition, profits of supply chain members and social welfare under the two investment strategies, with a view to providing theoretical reference for investment decisions of manufacturing enterprise.

2 Model Description

This research investigates a supply chain structure comprising a single upstream supplier and two downstream manufacturers that operate in a mutually competitive environment. The supplier provides an essential core component to both manufacturers, who then utilize this critical input in their respective production processes to manufacture finished end-products for distribution to the market. Within the market setting, the products offered by the two manufacturers fall within the same category and demonstrate a high degree of substitutability. Specifically, Product 1 is manufactured by a myopic manufacturer that tends to focus on short-term gains, while Product 2 is produced by a farsighted manufacturer that adopts a long-term strategic perspective. The competitive dynamics between these two manufacturers significantly influence both procurement and distribution decisions across the supply chain.

Unlike the shortsighted manufacturer who concentrate predominantly on immediate profits and quarterly returns, the farsighted manufacturer adopt a more comprehensive and strategic outlook. He place significantly greater emphasis on cultivating and securing sustainable long-term competitive advantages, while still thoughtfully accounting for and integrating short-term operational interests into his overarching strategic framework. To reinforce his core market competitiveness and break through existing industrial and competitive limitations, these proactive and forward-thinking manufacturer are commonly faced with two distinct—yet equally viable—strategic investment pathways. The first option is a technological innovation strategy, and the second option is an upward invasion strategy.

Under the strategy of technological innovation, the farsighted manufacturer invest a certain amount of money to carry out technological transformation of production processes and processes, so as to realize the optimal combination of production factors, thereby reducing product costs and improving production efficiency. Therefore, compared with shortsighted manufacturer, farsighted manufacturer have cost advantages.

Under the upward invasion strategy, the farsighted manufacturer invests a fixed sum of money to establish a stable supplier of its own parts (the supplier is a production department or subsidiary of the farsighted manufacturer), so as to realize the self-supply of parts. The upward invasion strategy leads to the reconstruction of the supply chain, and the supplier changes from the monopoly position of parts to the state of competing with farsighted manufacturer.

To emphasize the influence of the farsighted manufacturer's investment strategies on supply chain decision-making and social welfare, the scenario of the farsighted manufacturer prior to investment is regarded as the benchmark model. For the sake of descriptive convenience, we adopt superscripts N, C and E to denote the benchmark model, the technological innovation strategy model, and the upward invasion strategy model respectively, and subscripts S, $M1$ and $M2$ to represent the supplier, the short-sighted manufacturer, and the farsighted manufacturer respectively. Additionally, to derive the main findings, we present the following assumptions.

Assumption1. The unit component production cost of supplier is denoted by c_S, and wholesale price of component denoted by w. In view of the fact that the two manufacturers are in a stable competitive environment and their production processes and flow are similar, it is assumed that the other processing costs of each finished product produced by the two manufacturers are c.

Assumption2. Most studies use quadratic form to describe the innovation cost. We use $C(e)=ke^2/2$ to denote the innovation cost invested by farsighted manufacturer in technological innovation[5,13], where k is the innovation cost coefficient, and the innovation level is e ($e<c$), which can be expressed as the contribution of the transformation of production process of the farsighted manufacturer to the reduction of unit production cost of products[2,14]. Therefore, under the strategy of technological innovation, the unit production cost of farsighted manufacturer is $c-\sigma e$. $\sigma>0$ reflects the effect of technological innovation on reducing product cost. For the convenience of calculation, it is assumed that $\sigma=1$ without affecting the conclusion.

Assumption3. When the farsighted manufacturer chooses upward invasion strategy, it is assumed that the invasion cost is F, and the unit cost of producing the component by his own supplier is also c_S.

Assumption4. We use $\theta\in(0,1)$ to represent the product substitutability, and the larger value of θ brings more intense competition between the product 1 and product 2 in the market. Refer to the research of Abdul et al. [15], let demand function be given by $q_i=\xi-p_i+\theta p_{3-i}$, $i=1,2$, Where ξ is the initial market size for the product i, q_i and p_i represent selling quantity and the retail price of the product i.

Assumption5. To guarantee that the model results are non-negativity, we assume that the parameters satisfy the assumption $\xi-(c_S+c)>0$.

3 Models

3.1 Model N: Benchmark Model

Model N is the scenario before the farsighted manufacturer invest money, and the profit functions of the supplier, the shortsighted manufacturer, and the farsighted manufacturer are given as:

$$\pi_S = (w - c_S)[2\xi - (1-\theta)(p_1 + p_2)] \tag{1}$$

$$\pi_{M1} = (p_1 - w - c)(\xi - p_1 + \theta p_2) \tag{2}$$

$$\pi_{M2} = (p_2 - w - c)(\xi - p_2 + \theta p_1) \tag{3}$$

Under the framework of model N, a Stackelberg leader-follower game is established between the supplier and the two manufacturers. In this sequential decision-making structure, the supplier, acting as the Stackelberg leader, first determines the wholesale price w of the core component. Following this, the two manufacturers—one characterized by a shortsighted decision-making approach and the other by a farsighted perspective—engage in a Nash game as followers. Specifically, the shortsighted manufacturer sets the retail price p_1 for product 1, while the farsighted manufacturer determines the retail price p_2 for product 2. Using the method of backward induction to solve this multi-stage game, we derive the corresponding equilibrium outcomes. These results are systematically compiled and presented in Proposition 1.

Proposition 1. Under benchmark model, the equilibrium results of supply chain decision are as follows:

$$w^N = \frac{\xi - (1-\theta)(c - c_S)}{2(1-\theta)},\ p_1^N = p_2^N = \frac{\xi(3-2\theta) + (1-\theta)(c + c_S)}{2(1-\theta)(2-\theta)},$$

$$q_1^N = q_2^N = \frac{\xi - (1-\theta)(c + c_S)}{2(2-\theta)},\quad \pi_S^N = \frac{[\xi - (1-\theta)(c + c_S)]^2}{2(1-\theta)(2-\theta)},$$

$$\pi_{M1}^N = \pi_{M2}^N = \left[\frac{\xi - (1-\theta)(c + c_S)}{2(2-\theta)}\right]^2.$$

Proposition 1 indicates that prior to any significant technological advancement, the market positions of the two competing manufacturers are entirely symmetric, meaning that both firms operate under identical cost structures, market shares, and strategic capabilities. In such a balanced competitive environment, if one manufacturer attempts to unilaterally raise its price, it will inevitably lead to a noticeable decline in its sales volume, as consumers shift their demand to the relatively cheaper alternative offered by the rival firm. As a result, the profit margins of the price-increasing manufacturer will experience a significant contraction. Conversely, if one manufacturer decides to unilaterally lower its price in an effort to gain market advantage, this action will almost certainly provoke an immediate and retaliatory price reduction from the other manufacturer. This retaliatory behavior will ultimately trigger a price war, driving down overall industry profitability and creating a lose-lose outcome for both parties. Therefore, to avoid such detrimental scenarios and maintain stable market conditions, the two manufacturers mutually agree to establish an optimal retail price for their alliance—a coordinated pricing strategy that is acceptable to both and helps preserve collective profitability. Meanwhile, the supplier, by capitalizing on its monopolistic control over essential components, manages to extract higher profits from both manufacturers, further influencing the overall market dynamics.

Corollary 1. w^N , p_1^N , and p_2^N increases with θ ; q_1^N and q_2^N increases with θ ; π_S^N , π_{M1}^N, and π_{M2}^N increases with θ .

Corollary 1 indicates that despite the fact that the enhancement of product substitutability heightens the intensity of market competition, it boosts the customer mobility across the entire market, thereby generating a scale effect for the supply - chain system.

3.2 Model C: Technological Innovation Strategy Model

Upon the occurrence of technological progress, when a far-sighted manufacturer adopts a technological innovation strategy, the profit functions of the supplier, the short-sighted manufacturer, and the far - sighted manufacturer are presented as follows:

$$\pi_S = (w - c_S)[2\xi - (1-\theta)(p_1 + p_2)] \tag{4}$$

$$\pi_{M1} = (p_1 - w - c)(\xi - p_1 + \theta p_2) \tag{5}$$

$$\pi_{M2} = (p_2 - w - c + e)(\xi - p_2 + \theta p_1) - \frac{k}{2}e^2 \tag{6}$$

Under Model C, the game proceeds through a clearly defined sequence of stages. In the initial stage, the supplier takes the lead by establishing the wholesale price, which sets the foundational cost parameter for subsequent decisions w . Following this, in the second stage, the farsighted manufacturer makes its strategic choices, simultaneously determining both the optimal selling price p_2 and the appropriate level of innovation investment e . At the same time, the short-sighted manufacturer, operating with a different strategic outlook, focuses solely on setting its own selling p_1 price without considering long-term innovative development. As a result of this structured interaction and employing the method of backward induction to analyze the decisions from the final stage backward to the first, the outcomes described in Proposition 2 can be systematically derived.

Proposition 2. Within the technological innovation strategy model, the equilibrium outcomes of supply chain decision - making are as follows:

$$w^C = \frac{\xi - (1-\theta)(c - c_S)}{2(1-\theta)}, \quad e^C = \frac{(2+\theta)[\xi - (1-\theta)(c + c_S)]}{2[k(4-\theta^2) - (2-\theta^2)]},$$

$$p_1^C = \frac{\xi[3(2k-1) + \theta(2\theta - 2k\theta - k)] + (1-\theta)(2k - 1 + k\theta)(c + c_S)}{2(1-\theta)[k(4-\theta^2) - (2-\theta^2)]},$$

$$q_1^C = \frac{[k(2+\theta)-(1+\theta)][\xi-(1-\theta)(c+c_S)]}{2[k(4-\theta^2)-(2-\theta^2)]},$$

$$p_2^C = \frac{\xi[2(3k-2)-\theta(k-1)(1+2\theta)]+(1-\theta)(2k-\theta+k\theta)(c+c_S)}{2(1-\theta)[k(4-\theta^2)-(2-\theta^2)]},$$

$$q_2^C = \frac{k(2+\theta)[\xi-(1-\theta)(c+c_S)]}{2[k(4-\theta^2)-(2-\theta^2)]}, \quad \pi_S^C = \frac{[2k(2+\theta)-(1+\theta)][\xi-(1-\theta)(c+c_S)]^2}{4(1-\theta)[k(4-\theta^2)-(2-\theta^2)]},$$

$$\pi_{M1}^C = \left[\frac{[k(2+\theta)-(1+\theta)][\xi-(1-\theta)(c+c_S)]}{2[k(4-\theta^2)-(2-\theta^2)]}\right]^2, \pi_{M2}^C = \frac{k(2k-1)(2+\theta)^2[\xi-(1-\theta)(c+c_S)]^2}{8[k(4-\theta^2)-(2-\theta^2)]^2}.$$

Furthermore, to make the model economically meaningful, it is necessary for $e^C < c$. Let $k(\theta) = \frac{(2+\theta)[\xi-(1-\theta)(c+c_S)]+2c(2-\theta^2)}{2c(4-\theta^2)}$, when $k > k(\theta)$, there is $e^C < c$. Because $\frac{\partial k(\theta)}{\partial\theta} > 0$, $k(\theta)$ has a maximum value $\frac{3\xi+2c}{6c}$ at $\theta = 1$. Thus, for any $\theta \in (0,1)$, when $k > \frac{3\xi+2c}{6c}$, there is $e^C < c$.

Corollary 2. (a) $\frac{\partial w^C}{\partial k} = 0$, $\frac{\partial e^C}{\partial k} < 0$, $\frac{\partial p_1^C}{\partial k} > 0$, $\frac{\partial p_2^C}{\partial k} > 0$, $\frac{\partial q_1^C}{\partial k} > 0$, and $\frac{\partial q_2^C}{\partial k} < 0$.
(b) $\frac{\partial \pi_S^C}{\partial k} < 0$, $\frac{\partial \pi_{M1}^C}{\partial k} > 0$, and when $k \le \frac{2-\theta^2}{4-3\theta^2}$, $\frac{\partial \pi_{M2}^C}{\partial k} \ge 0$; otherwise, $\frac{\partial \pi_{M2}^C}{\partial k} < 0$.

Corollary 2 indicates that with the increase of innovation cost coefficient, the far-sighted manufacturer reduce costs and increase efficiency by taking measures of lowing innovation level and raising retail price of product 2. Nonetheless, with the gradual improvement of innovation cost coefficient, the effect of these measures is gradually decreasing. Meanwhile, the shortsighted manufacturer takes advantage of the situation to seize the market and moderately increases the price of product 1, so as to reduce the adverse impact of technological innovation strategy. However, The increase in retail prices of the two manufacturers lead to a decline in the total selling quantity, and thus lead to the shrinkage of supplier's profit.

3.3 Model E: Upward Invasion Strategy Model

When the farsighted manufacturer implement upward invasion strategy, the profit functions of the supplier, the shortsighted manufacturer, and the farsighted manufacturer are given as:

$$\pi_S = (w - c_S)(\xi - p_1 + \theta p_2) \tag{7}$$

$$\pi_{M1} = (p_1 - w - c)(\xi - p_1 + \theta p_2) \tag{8}$$

$$\pi_{M2} = (p_2 - c_S - c)(\xi - p_2 + \theta p_1) - F \tag{9}$$

Under model E, the Stackelberg leader-follower game is carried out between the supplier and the shortsighted manufacturer, and the Nash game is carried out between the two manufacturers. By backward induction, we can obtain the proposition 3.

Proposition 3. Under upward invasion strategy model, the equilibrium results of supply chain decision are as follows:

$$w^E = \frac{\xi(2+\theta) - c(1-\theta)(2+\theta) + c_S(1+\theta)(2-\theta)}{2(2-\theta^2)},\ p_1^E = \frac{\xi(3-\theta^2) + (1+\theta-\theta^2)(c+c_S)}{(2-\theta)(2-\theta^2)},$$

$$p_2^E = \frac{\xi(4+\theta-2\theta^2) + (4-\theta-\theta^2)(c+c_S)}{2(2-\theta)(2-\theta^2)},\ q_1^E = \frac{\xi-(1-\theta)(c+c_S)}{2(2-\theta)},$$

$$q_2^E = \frac{(4+\theta-2\theta^2)[\xi-(1-\theta)(c+c_S)]}{2(2-\theta)(2-\theta^2)},\quad \pi_S^E = \frac{(2+\theta)[\xi-(1-\theta)(c+c_S)]^2}{4(2-\theta)(2-\theta^2)},$$

$$\pi_{M1}^E = \left[\frac{\xi-(1-\theta)(c+c_S)}{2(2-\theta)}\right]^2,\ \pi_{M2}^E = \left[\frac{(4+\theta-2\theta^2)[\xi-(1-\theta)(c+c_S)]}{2(2-\theta)(2-\theta^2)}\right]^2 - F.$$

Corollary 3. (a) $\frac{\partial w^E}{\partial\theta} > 0$, $\frac{\partial p_1^E}{\partial\theta} > 0$, $\frac{\partial p_2^E}{\partial\theta} > 0$, $\frac{\partial w^E}{\partial\theta} < \frac{\partial w^N}{\partial\theta}$, $\frac{\partial p_1^E}{\partial\theta} < \frac{\partial p_1^N}{\partial\theta}$, and $\frac{\partial p_2^E}{\partial\theta} < \frac{\partial p_2^N}{\partial\theta}$.

(b) $\frac{\partial q_1^E}{\partial\theta} > 0$, $\frac{\partial q_2^E}{\partial\theta} > 0$, $\frac{\partial \pi_S^E}{\partial\theta} > 0$, $\frac{\partial \pi_{M1}^E}{\partial\theta} > 0$, and $\frac{\partial \pi_{M2}^E}{\partial\theta} > 0$.

Corollary 3 demonstrates that, under the upward invasion strategy, the equilibrium outcomes of supply chain decisions continue to exhibit a positive correlation with the degree of product substitutability. However, the adoption of the invasion strategy significantly attenuates the extent to which product substitutability influences pricing decisions. This moderating effect arises because the forward-looking manufacturer's entry into the component market disrupts the previously symmetric competitive relationship between the two manufacturers. By self-supplying key components, the invader secures a structural advantage in procurement costs, which alters the fundamental dynamics of inter-firm rivalry. This newly introduced factor—internal cost advantage—competes with and partially supersedes the role of product substitutability in shaping firms' pricing behaviors. As a result, the upward invasion strategy reduces the sensitivity of market competition to changes in substitutability, thereby diminishing the overall intensity with which product substitutability affects strategic pricing in the supply chain.

4 Comparative Analysis of Different Models

In this section, in addition to comparing the equilibrium results derived from Propositions 1, 2, and 3, we also analyze the profit and consumer surplus of the entire supply chain and contrast the social welfare across the three models.

4.1 Comparative Analysis of Equilibrium Results

Proposition 4. (a) $w^C = w^N$, $p_2^C < p_1^C < p_1^N = p_2^N$, $q_1^C < q_1^N = q_2^N < q_2^C$, and $q_1^C + q_2^C > q_1^N + q_2^N$.

(b) $\pi_S^C > \pi_S^N$, $\pi_{M1}^C < \pi_{M1}^N$, and $\pi_{M2}^C > \pi_{M2}^N$ always holds.

Proposition 4 clearly demonstrates that the technological innovation strategy is beneficial to the supplier as well as to the far-sighted manufacturer, while simultaneously imposing adverse effects on the short-sighted manufacturer. This outcome arises primarily because the technological innovation strategy intensifies the competitive dynamics between the two manufacturers. Specifically, the farsighted manufacturer leverages the cost-leadership advantage gained through innovation to substantially reduce its retail price. By employing a "penetration pricing" strategy, it successfully attracts a larger consumer base and seizes a greater market share. In response to this aggressive market encroachment, the short-sighted manufacturer is forced to implement price-reduction measures in an attempt to retain its original market position. However, due to its inherent cost disadvantage, which remains unmitigated by innovation, the short-sighted manufacturer finds itself at a significant drawback during the price competition. Although the wholesale price of the key component supplied by the upstream partner remains unchanged and is not directly influenced by the innovation strategy, the supplier nonetheless benefits from the overall expansion of market demand. This is reflected in the increased total quantity of the component ordered, thereby enhancing the supplier's profitability without altering its pricing structure.

Proposition 5. (a) $w^E < w^N$, $p_2^E < p_1^E < p_1^N = p_2^N$, $w^N - w^E = p_1^N - p_1^E$, and $q_1^E = q_1^N = q_2^N < q_2^E$.

(b) $\pi_S^E < \pi_S^N$, $\pi_{M1}^E = \pi_{M1}^N$.

(c) There exists a threshold F^{EN} such that when $F < F^{EN}$, we have $\pi_{M2}^E > \pi_{M2}^N$, where $F^{EN} = \dfrac{(1+\theta)(6+\theta-3\theta^2)[\xi-(1-\theta)(c+c_S)]^2}{4(2-\theta)(2-\theta^2)^2}$, and $\dfrac{\partial F^{EN}}{\partial\theta} > 0$.

Proposition 5 explicitly illustrates that, under the upward invasion strategy, the manufacturer's foresight and its capacity for self-supplying key components afford it a significant procurement cost advantage. This advantage, in turn, enhances its ability to capture market share through aggressive price competition. However, the analysis also reveals the existence of a critical invasion cost threshold. This threshold serves as a crucial reference point F^{EC}, indicating that managerial decision-making must be undertaken with caution. Specifically, if the actual invasion cost exceeds this identified threshold, the upward invasion strategy will no longer be economically viable or profitable, and its implementation could lead to diminished returns.

For the component supplier, in order to strengthen the market competitiveness of its products, it is compelled to implement a reduction in the wholesale price of components. This strategic move, while aimed at maintaining market share, leads to a significant compression of profit margins. At the same time, the long-sighted manufacturer, anticipating market shifts and seeking to optimize its own costs, further reduces its component orders. The combined impact of decreased order volumes and lower wholesale prices results in a notable decline in the supplier's overall profitability. It is particularly important to note that, because the short-sighted manufacturer adopts a price-following strategy, it does not contribute to absorbing the negative effects of these market dynamics. As a result, the supplier alone bears the full adverse consequences arising from the upward invasion strategy, without any shared burden or compensatory support from its downstream partners.

Proposition 5 provides a clearer and more detailed illustration of the relationship between the F^{EC} degree of product substitutability and the threshold value of the invasion cost, demonstrating that as substitutability intensifies, the corresponding invasion cost threshold also experiences a significant rise. This observable trend can be fundamentally attributed to the distinct and sustainable price advantages possessed by the far-sighted manufacturer, which are deeply rooted in their strategic market positioning and robust long-term planning capabilities. Such pricing advantages empower the manufacturer not only to capture a larger and more stable share of the market but also to substantially boost their overall profitability, especially in highly competitive environments. Consequently, the range of market and economic conditions under which the upward invasion strategy proves to be both viable and effective is considerably broadened. This expansion directly underscores that, in contexts where product substitutability is stronger, it becomes increasingly critical for the far-sighted manufacturer to proactively adopt and rigorously implement the upward invasion strategy, in order to sustain and further strengthen its competitive standing and market leadership.

Propositions 4 and 5 provide a clear and robust demonstration that the implementation of the two distinct investment strategies is capable of significantly amplifying the intensity of competition within the market environment. This effect is observed across multiple dimensions of market interaction, with one of the most prominent and readily observable outcomes being the escalation of rivalry among competing firms. Such rivalry is particularly evident in the strategic maneuvers related to product pricing, where participants increasingly engage in more aggressive and calculated pricing behaviors in response to shifting market dynamics. Furthermore, it is especially noteworthy that manufacturers who exhibit strategic foresight and maintain a trajectory of continuous technological innovation are positioned to adopt a more confident and assertive stance in their pricing strategies. This assertive approach not only enhances their competitive positioning but also exerts additional influence on the overall competitive landscape, thereby creating a feedback loop that further intensifies market competition.

Proposition 6. (a) $w^C > w^E$, $p_1^C > p_1^E$, and if $k > \dfrac{(2-\theta^2)(4-3\theta)}{(2-\theta)(4-\theta^2)}$, then $p_2^C > p_2^E$; otherwise, $p_2^C \le p_2^E$.

(b) $q_1^C < q_1^E$, and if $k > \dfrac{(2-\theta^2)(4+\theta-2\theta^2)}{(1+\theta)(2-\theta)(4-\theta^2)}$, then $q_2^C < q_2^E$; otherwise, $q_2^C \ge q_2^E$.

(c) $\pi_S^C > \pi_S^E$, $\pi_{M1}^C < \pi_{M1}^E$.

(d) There exists a threshold F^{EC} such that when $F < F^{EC}$, we have $\pi_{M2}^E > \pi_{M2}^C$; otherwise, $\pi_{M2}^E \le \pi_{M2}^C$, where $f(\theta) = \left[\dfrac{4+\theta-2\theta^2}{(2-\theta)(2-\theta^2)}\right]^2$, $F(k,\theta) = \dfrac{k(2k-1)(2+\theta)^2}{2[k(4-\theta^2)-(2-\theta^2)]^2}$, and $F^{EC} = \dfrac{[\xi-(1-\theta)(c+c_S)]^2}{4}\left[f(\theta)-F(k,\theta)\right]$.

Proposition 6 clearly demonstrates that, in the context of supply chain dynamics, the technological innovation strategy tends to be disadvantageous for the myopic manufacturer, while the upward invasion strategy proves to be unfavorable for the supplier. From the perspective of a far-sighted manufacturer, there is no single dominant investment strategy that consistently outperforms the other. Instead, the selection of the optimal investment strategy primarily depends on the magnitude of the invasion cost. Specifically, if the invasion cost is not higher than the predetermined threshold value F^{EC}, the benefits derived from choosing the upward invasion strategy are significantly greater, making it the more advantageous option. However, if the invasion cost exceeds this critical threshold F^{EC}, the potential for successfully invading the component market becomes substantially restricted due to the elevated expenses involved. Under such circumstances, it is more strategically beneficial and economically rational for the farsighted manufacturer to opt for the technological innovation strategy, as it allows for sustainable growth without incurring prohibitive costs.

4.2 Comparative Analysis of Social Welfare

Social welfare, the total profit and the consumer surplus of supply chain are respectively denoted by SW, π_T, and CS_T. According to the research of Esenduran et al. [16], social welfare function can be expressed as follows:

$$SW = \pi_T + CS_T \tag{10}$$

The total profit of supply chain is the sum of the profit of the supplier, the shortsighted manufacturer and the farsighted manufacturer, that is $\pi_T = \pi_S + \pi_{M1} + \pi_{M2}$, so the total profit of supply chain under different models are as follows:

$$\pi_T^N = \frac{(3-2\theta)[\xi-(1-\theta)(c+c_S)]^2}{2(1-\theta)(2-\theta)^2},\ \pi_T^C = G(k,\theta)[\xi-(1-\theta)(c+c_S)]^2,\ \text{“}\ \pi_T^E = g(\theta)[\xi-(1-\theta)(c+c_S)]^2 - F \tag{11}$$

where $G(k,\theta) = \dfrac{4k^2(2+\theta)^2(3-2\theta) - k(2+\theta)(18+\theta-11\theta^2) + 2(1+\theta)(3-2\theta^2)}{8(1-\theta)[k(4-\theta^2)-(2-\theta^2)]^2}$ and $g(\theta) = \dfrac{\theta^2 + 2(2-\theta^2)(7+2\theta-3\theta^2)}{4(2-\theta)^2(2-\theta^2)^2}$.

Consumer surplus refers to the difference between the price acceptable to consumers and the actual payment. The consumer surplus of product i can be expressed $(q_i)^2/2$. Consequently, the consumer surplus of the whole supply chain under different models is the sum of the consumer surplus of product 1 and product 2, which is $CS_T^I = \dfrac{(q_1^I)^2 + (q_2^I)^2}{2}$ ($I \in \{N, C, E\}$): that is,

$$CS_T^N = \frac{[\xi-(1-\theta)(c+c_S)]^2}{4(2-\theta)^2},\ CS_T^C = H(k,\theta)[\xi-(1-\theta)(c+c_S)]^2,\ CS_T^E = h(\theta)[\xi-(1-\theta)(c+c_S)]^2 \tag{12}$$

where $H(k,\theta) = \dfrac{(1-\theta)^2 + 2k(2+\theta)[k(2+\theta)-(1-\theta)]}{8[k(4-\theta^2)-(2-\theta^2)]^2}$ and $h(\theta) = \dfrac{\theta^2 + (2-\theta^2)[10+4\theta-5\theta^2]}{8(2-\theta)^2(2-\theta^2)^2}$.

Corollary 4. $\frac{\partial \pi_T^C}{\partial k} < 0$, $\frac{\partial \pi_T^E}{\partial F} < 0$, $\frac{\partial CS_T^C}{\partial k} < 0$, and $\frac{\partial CS_T^E}{\partial F} = 0$.

Corollary 4 provides a clear and comprehensive demonstration that, within the framework of the technological innovation strategy, both the overall profit and the consumer surplus of the entire supply chain exhibit a significant and consistent negative correlation with the innovation cost coefficient. This relationship indicates that as the innovation cost coefficient increases, there is a corresponding and proportional decrease in both the total profit generated by the supply chain and the consumer surplus, reflecting the economic burden imposed by higher innovation expenses. Conversely, under the upward invasion strategy, the profit of the entire supply chain is distinctly and negatively correlated with the invasion cost, meaning that higher invasion costs directly result in lower overall profitability for the supply chain participants. However, in a notable and intriguing contrast, the consumer surplus of the entire supply chain remains entirely unaffected by any variations in the invasion cost. This observation suggests that, regardless of how invasion costs fluctuate, consumer welfare remains stable and unchanged under this specific strategic approach, highlighting a key differential impact between corporate profits and consumer benefits in such scenarios.

Substituting Eqs. (11) and (12) into Eq. (10), we can obtain the social welfare under three models as follows:

$$SW^N = \frac{(7-5\theta)[\xi-(1-\theta)(c+c_S)]^2}{4(1-\theta)(2-\theta)^2},\ SW^C = \Phi(k,\theta)[\xi-(1-\theta)(c+c_S)]^2,\ SW^E = \phi(\theta)[\xi-(1-\theta)(c+c_S)]^2 - F \tag{13}$$

Where $\Phi(k,\theta) = \frac{2k^2(2+\theta)^2(7-5\theta) - k(2+\theta)(20+\theta-13\theta^2) + (1+\theta)(7-5\theta^2)}{8(1-\theta)[k(4-\theta^2)-(2-\theta^2)]^2}$ and $\phi(\theta) = \frac{3\theta^2 + (2-\theta^2)(38+12\theta-17\theta^2)}{8(2-\theta)^2(2-\theta^2)^2}$.

Proposition 7. (a) $SW^N < SW^C$ always holds.

(b) There exists a threshold F^{SW} such that when $(k,\theta) \in D$ and $F < F^{SW}$, we have $SW^E > SW^C$; otherwise, $SW^E \le SW^C$.

where $F^{SW} = [\phi(\theta) - \Phi(k,\theta)][\xi-(1-\theta)(c+c_S)]^2$, $D = \left\{ (\theta,k) \mid 0 < \theta < \theta^{SW}, k > \frac{B+\sqrt{B^2-8AC}}{4A(2+\theta)} \right\}$,

$$A = \frac{3\theta^2(1-\theta) + (2-\theta^2)(10-6\theta-15\theta^2+7\theta^3)}{2(2-\theta^2)^2},$$

$$C = \frac{(1-\theta)[3\theta^2 + (2-\theta^2)(38+12\theta-17\theta^2)] - (1+\theta)(2-\theta)^2(7-5\theta^2)}{(2-\theta)^2},$$

$B = \frac{(2-\theta^2)(36-34\theta-31\theta^2+21\theta^3) + 6\theta^2(1-\theta)}{(2-\theta)(2-\theta^2)}$, and $\theta^{SW} \in (0,1)$ is the root of the equation $\phi(\theta) - \Phi(+\infty,\theta) = 0$.

What needs to be explained here is that due to $\frac{\partial \Phi(k,\theta)}{\partial k} < 0$, and $\Phi(+\infty,\theta) = \lim_{k \to +\infty} \Phi(k,\theta) = \frac{7-5\theta}{4(1-\theta)(2-\theta)^2}$, it is not easy to get the analytic solution of the equation $\phi(\theta) - \Phi(+\infty,\theta) = 0$. However, through MATLAB software, we can gain that the numerical solution of the above equation is $\theta \approx 0.77$. Hence, let $\theta^{SW} = 0.77$, and the region D with $\phi(\theta) > \Phi(k,\theta)$ is as shown in Figure 1.

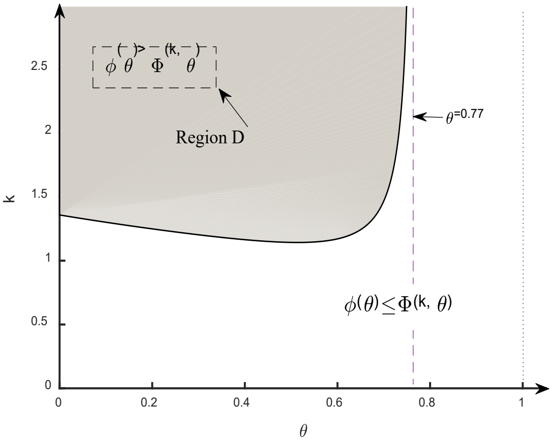


Fig. 1. Impact of k, θ on $\Phi(k,\theta)$ and $\phi(\theta)$.

5 Numerical Analysis

In this section, the sensitivity analysis is carried out to present how the discussed parameters influence the optimal operational decisions of supply chain through numerical analysis. we examine the impact of product substitutability, innovation cost coefficient and invasion cost on the profit of supply chain members and social welfare. The parameters setting is as follows: $\xi = 30$, $c_S = 10$, and $c = 15$.

5.1 Sensitivity Analysis of Innovation Cost Coefficient and Product Substitution

Table 1. Influence of innovation cost coefficient on equilibrium decision of model C when $\theta = 0.5$.

k	w^C	p_1^C	e^C	p_2^C	q_1^C	q_2^C	$w^C - w^N$	$p_1^C - p_1^N$	$p_2^C - p_2^N$	$q_1^C - q_1^N$	$q_2^C - q_2^N$
1.50	27.50	47.58	5.65	45.32	5.08	8.47	0	-0.75	-3.01	-0.75	2.64
2.00	27.50	47.83	3.80	46.30	5.33	7.61	0	-0.50	-2.03	-0.50	1.78
2.50	27.50	47.95	2.87	46.80	5.45	7.17	0	-0.38	-1.53	-0.38	1.34
3.00	27.50	48.03	2.30	47.11	5.53	6.91	0	-0.30	-1.22	-0.30	1.08

In Table 1, take values of $\theta = 0.5$, we examine the influence of innovation cost coefficient k on equilibrium decision of model C by increasing k from 1.50 to 3.00.

Table 1 shows that under model C, there is always $p_1^C > p_2^C$, and the supplier's wholesale price w^C is not affected by k. In addition, with the increase of k, the retail price and selling quantity of the shortsighted manufacturer increase slightly. Although the retail price of the farsighted manufacturer is gradually increasing, his innovation level and selling quantity are obviously declining. Another observation is that with the increase of k, the difference between model N and model C in retail price and selling quantity gradually become lower. This indicates that although technology innovation strategy can bring price advantage to the farsighted manufacturer, which gradually becomes weak with the increase of k.

In Table 2, take values of $k = 2$, we investigate the impact of product substitutability θ on pricing decision and demand of three models by increasing θ from 0.30 to 0.70.

Table 2. Influence of product substitutability on pricing decision and demand when $k = 2$.

θ	model N			model C						model E				
	w^N	$p_1^N(p_2^N)$	$q_1^N(q_2^N)$	e^C	w^C	p_1^C	p_2^C	q_1^C	q_2^C	w^E	p_1^E	p_2^E	q_1^E	q_2^E
0.30	18.93	37.61	3.68	2.43	18.93	37.42	36.36	3.49	4.86	17.53	36.20	32.93	3.68	7.93
0.40	22.50	42.19	4.69	3.08	22.50	41.87	40.58	4.37	6.16	19.78	39.47	35.39	4.69	10.39
0.50	27.50	48.33	5.83	3.80	27.50	47.83	46.30	5.33	7.61	22.50	43.33	38.33	5.83	13.33
0.60	35.00	57.14	7.14	4.61	35.00	56.38	54.61	6.38	9.22	25.85	48.00	41.90	7.14	16.90
0.70	47.50	71.15	8.65	5.51	47.50	70.05	68.01	7.55	11.03	30.12	53.77	46.32	8.65	21.32

Table 2 shows that with the increase of θ, the equilibrium solutions all increase gradually, and the selling quantity q_1^E and q_2^E of model E are marked increase. Another observation is that there are always $w^N = w^C > w^E$, $p_1^N > p_1^C > p_1^E$, $p_2^N > p_2^C > p_2^E$, $p_1^C > p_2^C$, and $p_1^E > p_2^E$, thereby reflecting the strengthening of competition, which implies that two investment strategies can intensify the market competition in different degrees, and the enterprise with technological progress is more aggressive in pricing.

Although Table 2 demonstrates the impact of product substitutability θ on pricing decision, it cannot fully show the influence of two investment strategies on market competition. Hence, In Table 3, we explore the impact of product substitutability increment $\Delta\theta$ on price increment (i.e., Δw^I, Δp_i^I) by increasing j from 1 to 4. To facilitate comparative analysis, we use the difference $\Delta\theta = \theta_{j+1} - \theta_j$ to indicate product substitutability increment, and use the difference $\Delta w^I = w^I(\theta_{j+1}) - w^I(\theta_j)$, and $\Delta p_i^I = p_i^I(\theta_{j+1}) - p_i^I(\theta_j)$ to indicate price increment under three models. Therefore, according to Table 2, let $\theta_1 = 0.3$, $\theta_{j+1} = \theta_j + 0.1$ ($j = 1,2,3,4$). Obviously, it is easy to get $\Delta\theta = 0.1$.

Table 3. Numerical results in different j for $\Delta w^I = w^I(\theta_{j+1}) - w^I(\theta_j)$ and $\Delta p_i^I = p_i^I(\theta_{j+1}) - p_i^I(\theta_j)$ when $k = 2$.

j	model N			model C			model E		
	Δw^N	Δp_1^N	Δp_2^N	Δw^C	Δp_1^C	Δp_2^C	Δw^E	Δp_1^E	Δp_2^E
1	3.57	4.58	4.58	3.57	4.45	4.22	2.25	3.27	2.46
2	5.00	6.14	6.14	5.00	5.96	5.72	2.72	3.86	2.94
3	7.50	8.81	8.81	7.50	8.55	8.31	3.35	4.67	3.57
4	12.50	14.01	14.01	12.50	13.67	13.40	4.27	5.77	4.42

Table 3 shows that $\Delta w^N = \Delta w^C > \Delta w^E$, $\Delta p_1^N > \Delta p_1^C > \Delta p_1^E$, and $\Delta p_2^N > \Delta p_2^C > \Delta p_2^E$ always hold, which implies that with the enhancement of product substitutability, the increase of selling price under the two investment strategies has obviously slowed down. This means that the two investment strategies not only intensify market competition, but also weaken the influence of product substitutability on pricing decision. Moreover, compared to the technological innovation strategy, the upward invasion strategy breaks the monopoly position of the supplier on component, which makes the competitive advantage of the farsighted manufacturer more obvious, thus greatly weakening the intensity of product substitutability affecting market competition.

5.2 The Analysis of Profit of Supply Chain Members and Social Welfare

In this subsection, we discuss the profits of supply chain members and social welfare. The results of our analysis are illustrated in Fig. 2 to Fig. 5.

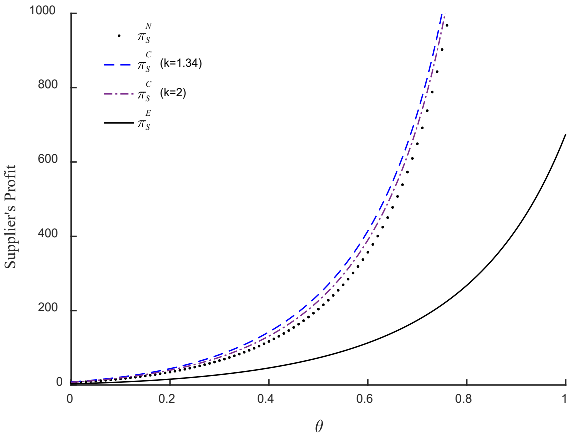


Fig. 2. Impact of k, θ on the supplier's profit

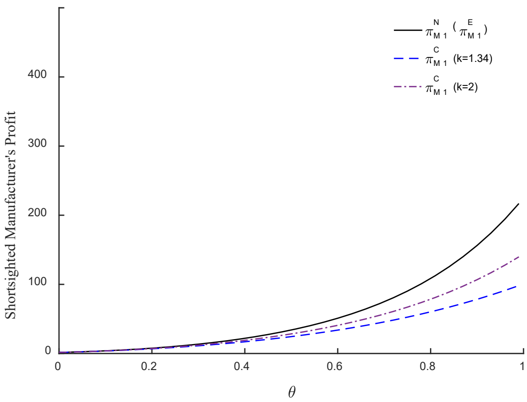
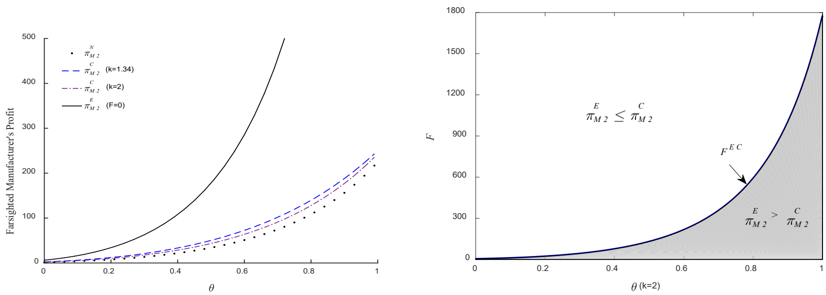


Fig. 3. Impact of k , θ on the shortsighted manufacturer's profit

In Fig. 2, we can see that the profit of supplier is the highest under technological innovation strategy and the lowest under upward invasion strategy, so technological innovation strategy is more beneficial to supplier. And the lower value of k brings larger profit for the supplier under technological innovation strategy.

In Fig. 3, we can see that the profit of the shortsighted manufacturer is the same under model E and model N, and it is higher than that under model C. Therefore, technological innovation strategy is unfavorable for the shortsighted manufacturer.



(a) (b)

Fig. 4. Impact of k , θ and F on the investment strategy choice of the farsighted manufacturer

Fig.4(a) shows that, for the farsighted manufacturer, the profit would increase along the increasing value of θ under three models, and the large value of k leads the farsighted manufacture to pay higher innovation cost under model C, which makes the profit decreased. In addition, no matter what the value of k is, when $F = 0$, the profit of the farsighted manufacturer is the highest under model E and the lowest under model N.

Taking value of $k = 2$, the influence of θ and F on the investment strategy choice for the farsighted manufacturer is presented in Figure 4(b). From Fig.4(b), we know that when $F < F^{EC}$, there is $\pi_{M2}^{E} > \pi_{M2}^{C}$ holds, which implies that choosing upward invasion strategy is beneficial to the farsighted manufacturer in this case. Conversely, there is $\pi_{M2}^{E} \le \pi_{M2}^{C}$ holds, which implies that choosing technological innovation strategy benefits the farsighted manufacturer. However, the larger value of θ leads to higher threshold F^{EC} , which means that the more intense the market competition is, the more necessary it is for the farsighted manufacturer to implement the upward invasion strategy.

Since the social welfare under model N is lower than that under model C, we only explore the influence of parameters θ , k , and F on social welfare under model C and model E. Take values of $k = 1.34$ or $k = 2$, according to $\Phi(k,\theta) = \phi(\theta)$, we can get $\theta \approx 0.68$ or $\theta \approx 0.74$ accordingly. The influence of k , θ , and F on the social welfare of Model C and Model E is shown in Fig. 5.

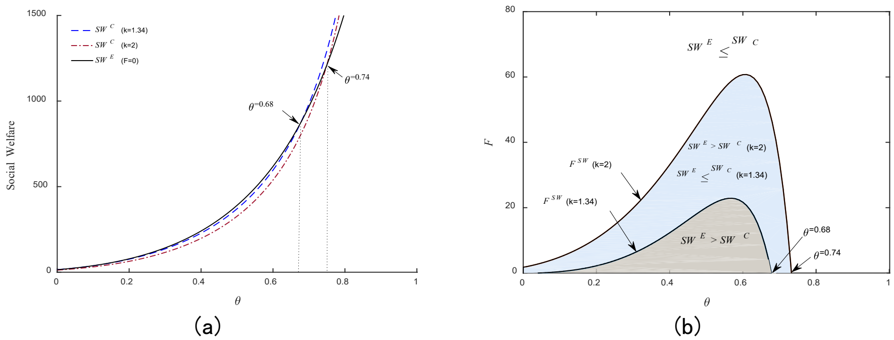


Fig. 5. Impact of k , θ and F on social welfare

In Fig.5(a), if $F = 0$, then we can see that when $k = 1.34$ (or $k = 2$), the social welfare under the two input strategies is equal at $\theta = 0.68$ (or $\theta = 0.74$). When the product substitutability is lower than this value, the social welfare under the upward invasion strategy is higher, whereas the social welfare under the technological innovation strategy is higher.

From Fig.5(b), we can see that threshold F^{SW} first increases and then decreases with θ , and when $F < F^{SW}$, there is $SW^E > SW^C$, which indicates that the social welfare of upward invasion strategy has an advantage in this case. Meanwhile, with the increase of innovation cost coefficient k , the curve F^{SW} becomes sharper and steeper, and thus the area where social welfare of upward invasion strategy has an advantage gradually expands.

6 Conclusions

To gain a more comprehensive understanding of the influence of the farsighted manufacturer's investment strategy on supply chain decision-making and social welfare, this study examines three supply chain models, namely, the benchmark model, the technological innovation strategy model, and the upward invasion strategy model. The equilibrium results are derived, and the impacts of market competition, innovation cost coefficient, and invasion cost on the farsighted manufacturer's investment strategy selection and social welfare are analyzed. The reasons why the two investment strategies can intensify market competition and weaken the influence of product substitution intensity on market competition are expounded. Intriguingly, it is found that the decision-making of the short - sighted manufacturer is not affected by the upward invasion strategy of the farsighted manufacturer, and the reasons for this phenomenon are also explained.

The research findings yield several management insights. Firstly, in comparison with the benchmark model, the two investment strategies can lower the selling price and stimulate the release of consumption demand across the entire supply chain. However, the technological innovation strategy is more conducive to enhancing the product innovation level. Secondly, although the technological innovation strategy is beneficial to the farsighted enterprise, as the innovation cost coefficient increases, the advantages of the technological innovation strategy become less prominent. Therefore, the farsighted enterprise should not be overly fixated on price competition but should endeavor to reduce the innovation cost coefficient and improve the efficiency of technological innovation. Only in this manner can the advantages of the technological innovation strategy be emphasized. Thirdly, the upward invasion strategy can restructure the supply chain system. Nevertheless, when an enterprise opts for an invasion strategy, the invasion cost is a crucial factor to consider. Excessive invasion cost is neither beneficial to the enterprise's profit nor to social welfare.

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