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Research Article

An Empirical Study on Optimal the Allocations in Advertising and Operation Innovation on Supply Chain Alliance for Complex Data Analysis

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Effective and efficient closed-loop supply chain processes can provide a significant competitive edge for companies. This study considered three investment strategies in the process of initiating closed-loop supply chain alliances. The results showed that a promised proportion has a significant effect on investment decisions under a pure investment strategy. Furthermore, a reasonable promised proportion can coordinate the supply chain under a pure innovation strategy but cannot in a pure advertising strategy. Upstream (i.e., innovation) investments decrease wholesale and retail prices, while downstream ones increase retail and wholesale prices. Increasing innovation investment can transform benefits to the downstream, while increasing advertising investment may cause opportunism. A hybrid investment strategy balances upstream and downstream investment simultaneously and provides insights into optimizing the supply chain system in investments.

1. Introduction

Current societies and enterprises are paying increasing attention to environmental pollution. Thus, more attention is being paid to product reuse management. Some types of government legislation require manufacturers to deal with their end-of-life products and waste production. Many manufacturing firms have thus begun to focus on product recovery management, including returns, refurbishing, recycling, remanufacturing, and marketing, to comply with rigid environmental regulations [1]. Product recycling can in fact benefit a company if it is handled properly. Dell reported that since 2014, it has recycled 4.2 million pounds, reduced its product carbon footprint by 11%, and achieved cost savings through its recycling supply chain. Meanwhile, 14 auto part remanufacturing enterprises and 35 home appliance manufacturers in China, which had been identified as national e-waste collection and recycling pilot projects, have saved almost 155 billion RMB in environmental benefits per year [2, 3]. Hence, closed-loop supply chain issues have gained considerable attention among both academia and practitioners due to the positive environmental effects [4–6] and economic benefits [7].

In practice, it is an effective way to implement closed-loop supply chains with suitable partners to copy with rigid environment regulations and enjoy the economic benefits. Hence, this study focused on building the closed-loop supply chains via upstream and downstream investment strategies.

The extant research on closed-loop supply chain issues has mainly focused on designing, planning [8–10], and surveying [11]. For a review of reverse logistics and closed-loop supply chain literature, refer to Guide & Wassenhove [12], Agrawal et al. [13], Govindan et al. [4] and Islam & Huda [8].

Reverse-logistic management issues in traditional supply chain management refer to remanufactured products [14, 15]. A complete literature review in this field can be found in Fleischmann et al. [16], Guide et al. [17], Souza [18], Stindt & Sahamie [19] and Marić & Opazo-Basáez (2019). This stream of literature has focused on network design [20, 21], inventory control [22], reverse channel structure [23, 24], simulation (Abid et al., 2019), price, and coordination [25, 26]. In practice, operational innovation and advertising are both often used to build a company's competitive advantage, i.e., advertisement aims to stimulate demand or opens up the sales market, while operational innovation can improve a company's performance through reducing costs. However, these two investment decisions occur at the front and back ends of the supply chain, respectively. Advertising decisions and operational innovation decisions are frequently encountered and widely discussed topics in operations management. Inspired by such research, this study adopted a similar approach to consider the problems of upstream and downstream investment allocation in the supply chain.

Advertising can build a stock of goodwill and promotes product sales. Cooperative advertising is a coordinating mechanism in the marketing channel that is widely used in supply chain management. For example, coop advertising was first adopted to examine promotion effect problems in supply chains (Berge, 1973). Most of the literature has focused on evaluating the impact of advertising investment on market demand (Dai & Chao, 2013; [27, 28]). Consistent with these assumptions, we assumed that advertising investment could improve the volume of sales, and then we considered advertising investment decisions in supply chains.

Operational innovation in supply chains pertains to improvements in quality, yield, delivery time, and supply cost [29]. Little attention was paid to the recycling and reuse of waste products in the early stage, leading to low reproduction efficiency. With the increasing emphasis on product recycling, more and more research has suggested that it is necessary to improve the processes for recycled products via innovation investment [30]. A comprehensive performance measurement system was developed to measure the performance of firms with respect to innovation policy and marketing strategy [31]. Most researchers have realized that innovation investment can result in either cost reduction or quality improvement [31–33]. Based on the relations between innovation and product cost found in the literature [33], we considered innovation investment decisions in the supply chain.

Note that the two streams of literature mentioned above either considered advertising investment or innovation investment in closed-loop supply chains. However, a closed-loop supply chain alliance can simultaneously consider innovation investment in the upstream and advertising investment in the downstream to enjoy the economic benefits. How to allocate investments on advertising and operational innovation is one of challenges of closed-loop supply chain systems. Any initiator of a closed-loop supply chain needs to weigh investment decisions on upstream and downstream simultaneously in the supply chain. Hence, this study focus on the allocations on/between advertising and operation innovation on supply chain, and investigates the optimal investment allocation on/between the two decisions within a supply chain system.

The rest of this paper is organized as follows. Section 1 presents the model descriptions. The model analysis will examined the investment decision under pure strategies as well as under mixed strategies in Section 2. Section 3 presents numerical results based on the theoretical results. A summary of this research and discuss future research directions are conducted in Section 4. Some proofs are presented in the supplementary materials (available here).

2. Model Description

Consider a supply chain system composed of a manufacturer and a seller, in which the manufacturer, possessing manufacturing/remanufacturing production lines, can directly produce products with new components and remanufacture products with used products; it can then distribute new products and recover used products through the seller. Consistent with Xu et al. [33], one returned product can be remanufactured into one remanufactured product. The original remanufacture cost is c and can be reduced to $c - \beta x (0 < \beta \ll 1)$ with investing operational innovation x^2 to improve the remanufacturing production lines [32]. Under a price-sensitive market, sales in the market are $Q = D - kp$ and can increase to $Q + \alpha y (0 < \beta \ll \alpha < 1, \alpha < k)$ as advertising investment increases to y^2 [32, 34, 35], where the potential initial market is D, and the retile price is p.

There are two scenarios for building the supply chain alliance. A leading manufacturing enterprise may invite a seller to join the alliance and promise to bear part of the advertising investment for the retailer to alleviate the seller's investment risk. A seller may actively request to join the alliance and promise to bear part of the innovation investment for improving technology to reduce reproduction costs and then hope to decrease the wholesale price for itself. Then, the supply chain alliance must make allocation decisions in investments in advertising and innovation to optimize alliance performance.

3. Model Analysis

3.1. Pure Innovation Investment Strategy. A supply chain center uses an innovation investment strategy to reduce remanufacturing costs. Under a price-sensitive market, the central planner makes the innovation investment x^2 as

$$\pi^{SI}(p, x) = (p - c + \beta x)(D - kp) - x^2. \tag{1}$$

Lemma 1. *A pure innovation investment strategy has optimal innovation investment and retail price as follows:*

$$p^{SI*} = \frac{2D + 2kc - Dk\beta^2}{\left(k\left(4 - k\beta^2\right)\right)}, x^{SI*} = \frac{\beta(D - kc)}{4 - k\beta^2}. \tag{2}$$

To build the supply chain alliance, the seller promises to undertake part of the investment to improve the remanufacturing production line. Then, the decision-making sequence is as follows: (1) The seller promises to undertake a proportion of the investment (i.e., t) and becomes responsible for

recycling used products in advance. (2) The manufacturer then determines innovation investment x^2 and wholesale price w. (3) The seller finally determines the retail price in the price-sensitive market.

The seller's decision equation is as follows:

$$\pi_r^{SI}(p \mid x, w, t) = (p - w)(D - kp) - tx^2. \tag{3}$$

The manufacturer's decision equation is as follows:

$$\pi_m^{SI}(w, x \mid p, Q) = (w - c + \beta x)(D - kp) - (1 - t)x^2. \tag{4}$$

Lemma 2. *Under a pure innovation investment strategy, the supply chain alliance exists in equilibrium for both the manufacturer and seller as follows:*

$$\begin{aligned} p_t^{SI*} &= \frac{2ck(-1+t) + D\left(-6 + \beta^2 k + 6t\right)}{k\left(-8 + \beta^2 k + 8t\right)}, \\ Q_t^{SI*} &= \frac{2(D - ck)(-1+t)}{-8 + \beta^2 k + 8t}, \\ x_t^{SI*} &= \frac{\beta(-D + ck)}{-8 + \beta^2 k + 8t}, \\ w_t^{SI*} &= \frac{4ck(-1+t) + D\left(-4 + \beta^2 k + 4t\right)}{k\left(-8 + \beta^2 k + 8t\right)}. \end{aligned} \tag{5}$$

The equilibrium suggests that manufacturer would made operational innovations x_t^{SI*} and then charged the wholesale price w_t^{SI*} with the promised undertaking proportion t.

Proposition 3. *Under a pure innovation investment strategy, the promised proportion has a significant effect on the innovation investment. Specifically, $x^{SI*} \geq x_t^{SI*}$ with $t \leq 1/2$, and $x^{SI*} < x_t^{SI*}$ with*

$$1/2 < t < 1. \tag{6}$$

Proposition 4. *Under a pure innovation investment strategy, the supply chain can be coordinated by promising an appropriate proportion.*

The promised proportion t can stimulate the manufacturer to join the alliance. The more the proportion undertaken by the retailer, the more operational innovation would be. A reasonable promised proportion can be made to coordinate the decentralized decisions.

3.2. Pure Advertising Investment Strategy. A supply chain center can then use an advertising investment strategy to stimulate market sales, which undoubtedly increases the cost of the supply chain. Under a price-sensitive market, the supply chain center optimizes advertising investment y^2:

$$\pi^{SA}(p, y) = (D - kp + \alpha y)(p - c) - y^2. \tag{7}$$

Lemma 5. *A pure advertising investment strategy has optimal advertising investment y^* and retail price p^* as follows:*

$$p^{SA*} = \frac{2D + 2ck - \alpha^2 c}{4k - \alpha^2}, y^{SA*} = \frac{\alpha(D - ck)}{4k - \alpha^2}. \tag{8}$$

To build a supply chain alliance, the manufacturer promises to undertake part of the advertising investment. Then, the decision-making sequence is as follows: (1) The manufacturer promises a proportion of the advertising investment (i.e., t) and the wholesale price (i.e., w). (2) Then, the seller determines the retail price and the advertising investment.

The seller's decision equation

$$\pi_r^{SA}(p, y \mid w, t)(D - kp + \alpha y)(p - w) - (1 - t)y^2. \tag{9}$$

The manufacturer's decision equation

$$\pi_m^{SA}(w) = (D - kp + \alpha y)(w - c) - ty^2. \tag{10}$$

Lemma 6. *Under a pure advertising investment strategy, the supply chain alliance exists in equilibrium as follows:*

$$\begin{aligned} p_t^{SA*} &= \frac{2k(3d + ck)(-1+t)^2 + \alpha^2\left(ck(-1+t) + D(-1+2t)\right)}{k\left(8k(-1+t)^2 + \alpha^2(-2+3t)\right)}, \\ y_t^{SA*} &= -\frac{\alpha(D - ck)(-1+t)}{8k(-1+t)^2 + \alpha^2(-2+3t)}, \\ Q_t^{SA*} &= \frac{2k(D - ck)(-1+t)^2}{8k(-1+t)^2 + \alpha^2(-2+3t)}, \\ w_t^* &= \frac{4k(D + ck)(-1+t)^2 + \alpha^2\left(ck(-1+t) + D(-1+2t)\right)}{k\left(8k(-1+t)^2 + \alpha^2(-2+3t)\right)}. \end{aligned} \tag{11}$$

The seller would made the advertising investment y_t^{SA*} and then charged the retail price p_t^{SA*} to make the market sale as Q_t^{SA*} with manufacturer's promised proportion t and charged wholesale price w_t^*.

Proposition 7. *Under a pure advertising investment strategy, the promised proportion has a significant effect on advertising investment. Specifically, $y_t^{SA*} \geq y^{SA*}$ with $t \geq 1/2$; $y_t^{SA*} < y^{SA*}$ with $t < 1/2$.*

Proposition 8. *Under a pure advertising investment strategy, the supply chain alliance cannot be coordinated by the promised proportion.*

Similarly, the promised proportion t can stimulate seller to join the alliance with the coordinative advertising. The more the proportion undertaken by manufacturer, the more advertising investment would be. Unfortunately, the promised proportion cannot coordinate the decentralized decisions.

3.3. Hybrid Investment Strategy. A supply chain alliance can make decisions simultaneously—that is, make innovation investments in the upstream and advertising investments in the downstream. Under a hybrid investment strategy, the

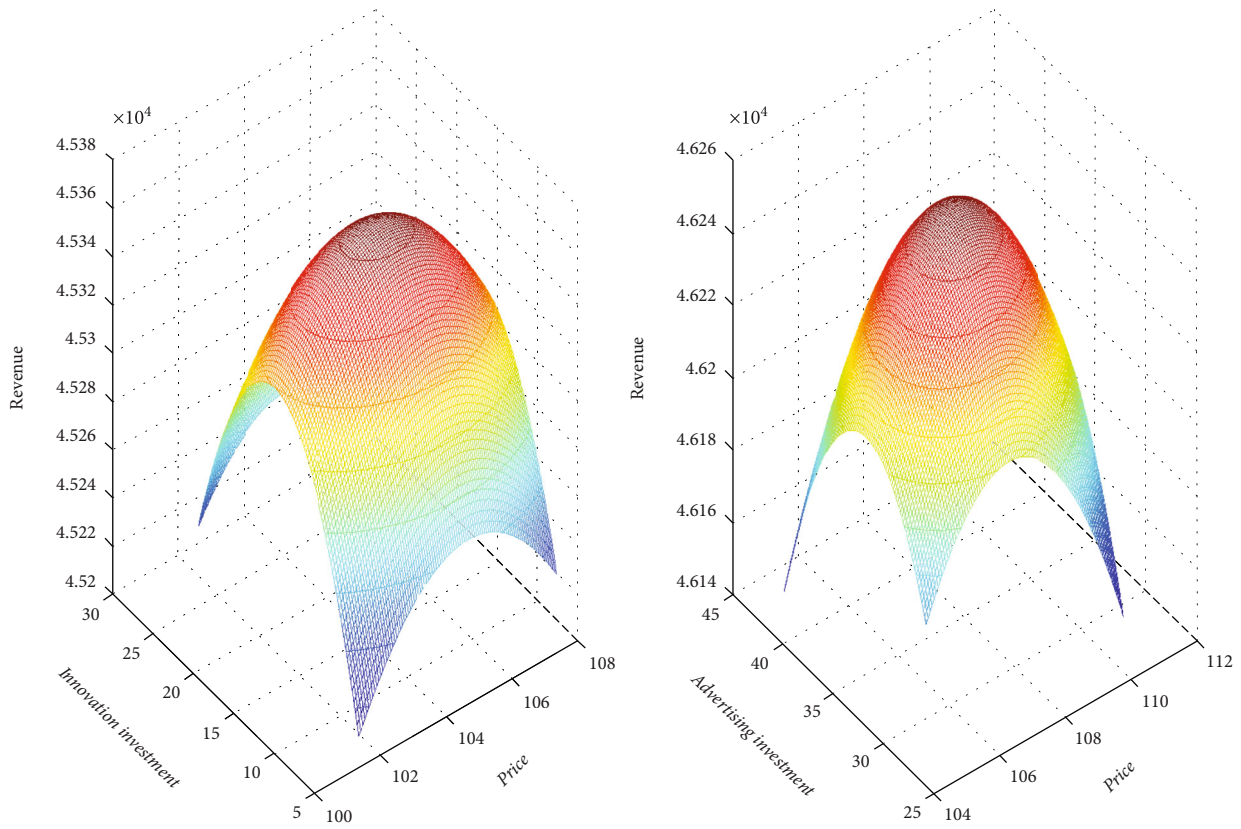

Figure 1: Revenue curves in pure innovation strategies (left) and pure advertising strategies (right).

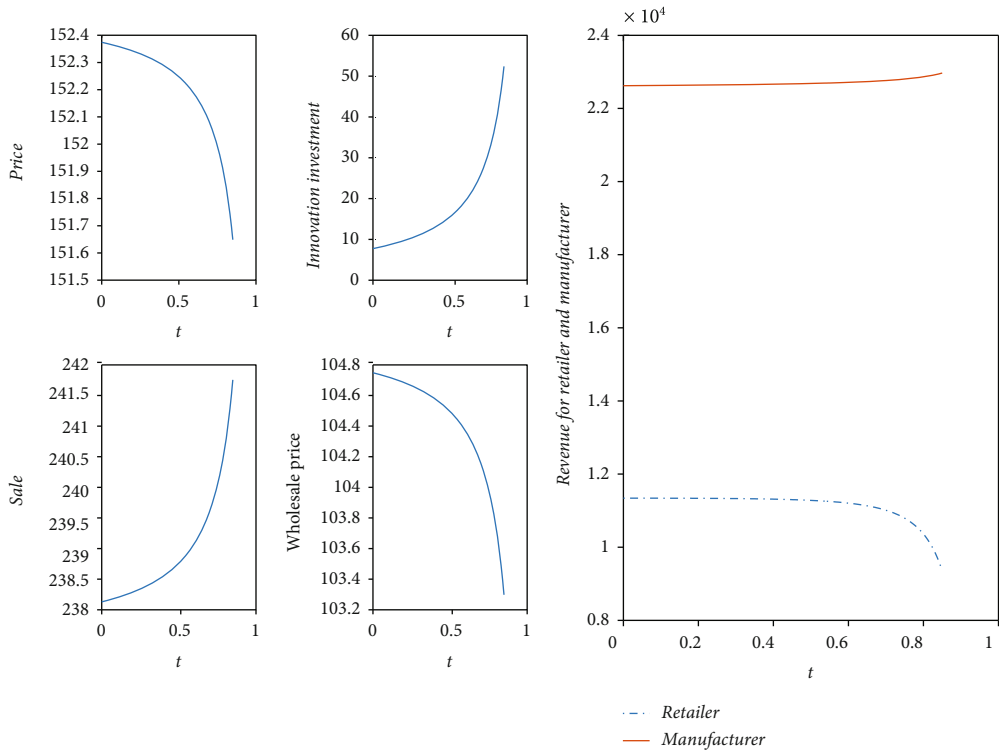

Figure 2: Effects of promised proportions under a pure innovation strategy.

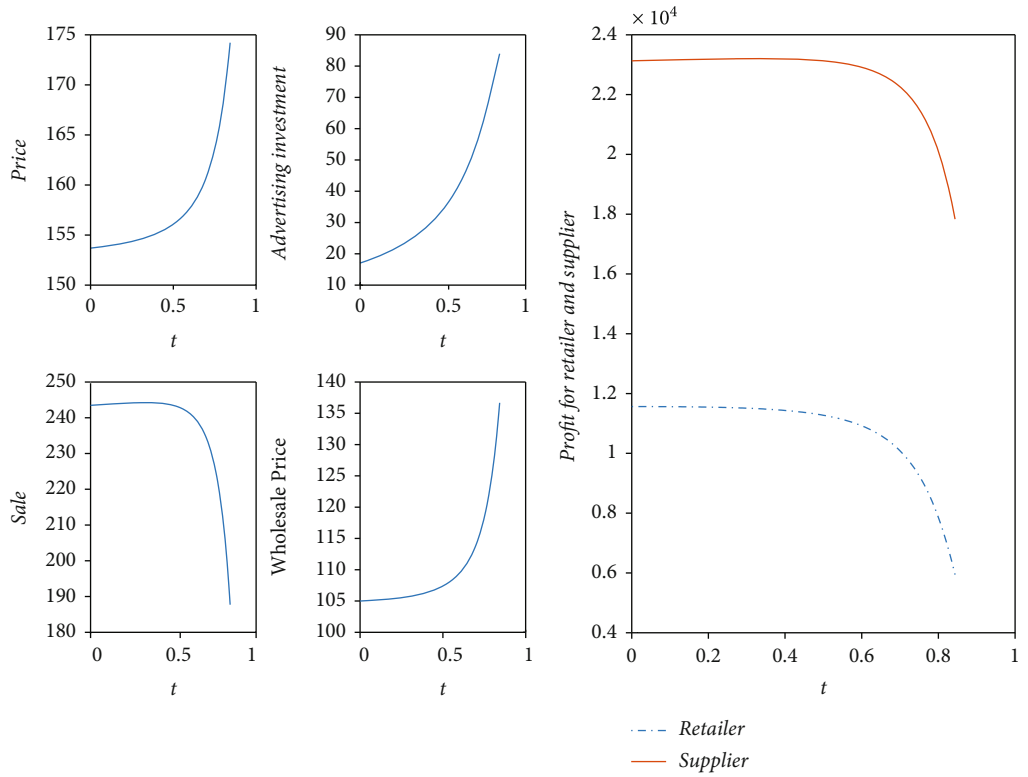

Figure 3: Effects of shared proportion under a pure advertising strategy.

supply chain center optimizes the equation for innovation investment and advertising investment:

$$\pi^{DC}(p,x,y) = (p - c + \beta x)(D - kp + \alpha y) - x^2 - y^2. \quad (12)$$

Theorem 9. *Under hybrid investment strategies, the supply chain has the optimal investment and retail price, as*

$$\begin{aligned} x^{DC*} &= \frac{\beta k(-D + ck)}{\alpha^2 + k\left(-4 + \beta^2 k\right)}, \\ y^{DC*} &= \frac{\alpha(-D + ck)}{\alpha^2 + k\left(-4 + \beta^2 k\right)}, \\ p^{DC*} &= \frac{\alpha^2 c - 2ck + D\left(-2 + \beta^2 k\right)}{\alpha^2 + k\left(-4 + \beta^2 k\right)}. \end{aligned} \quad (13)$$

Proposition 10. *Under a hybrid strategy, the innovation investment is less than that in a pure innovation strategy, while the advertising investment is larger than that in a pure advertising strategy in centralized decisions.*

Compared with pure strategy, the supply chain center would adjust the investment structure by decreasing innovation investments but increasing advertising investment due to the sensitivity under hybrid strategy.

Propositions 3 and 7 suggest that the initiator's promised proportion has a significant effect on the follower's investment but cannot avoid the emergence of opportunism. Hence, the supply chain alliance can make the upstream fully responsible for the innovation investment and the downstream fully responsible for the advertising investment. Then, the sequence of decision-making is as follows: (1) The manufacturer first promises to undertake innovation investment to improve the reproduction line, and (2) the seller sets the advertising investment and retail price according to the manufacturer's promise and the market situation. The decision functions for both parties are, respectively,

$$\pi_r^{DD}(p,y) = (D - kp + \alpha y)(p - w) - y^2, \quad (14)$$

$$\pi_s^{DD}(w,x) = (D - kp + \alpha y)(w - c + \beta x) - x^2. \quad (15)$$

Theorem 11. *Under a hybrid strategy, the supply chain exists in equilibrium for both manufacturer and seller as*

$$\begin{aligned} x^{DD*} &= \frac{\beta k(-D + ck)}{2\alpha^2 + k\left(-8 + \beta^2 k\right)}, \\ w^{DD*} &= \frac{\alpha^2(D + ck) + k\left(-4ck + D\left(-4 + \beta^2 k\right)\right)}{k\left(2\alpha^2 + k\left(-8 + \beta^2 k\right)\right)}, \\ y^{DD*} &= \frac{\alpha(-D + ck)}{2\alpha^2 + k\left(-8 + \beta^2 k\right)}, \\ p^{DD*} &= \frac{\alpha^2(D + ck) + k\left(-2ck + D\left(-6 + \beta^2 k\right)\right)}{k\left(2\alpha^2 + k\left(-8 + \beta^2 k\right)\right)}, \\ Q^{DD*} &= \frac{2k(-D + ck)}{2\alpha^2 + k\left(-8 + \beta^2 k\right)}. \end{aligned} \quad (16)$$

Proposition 12. *Under a hybrid strategy, innovation and advertising investments are both larger than those in a*

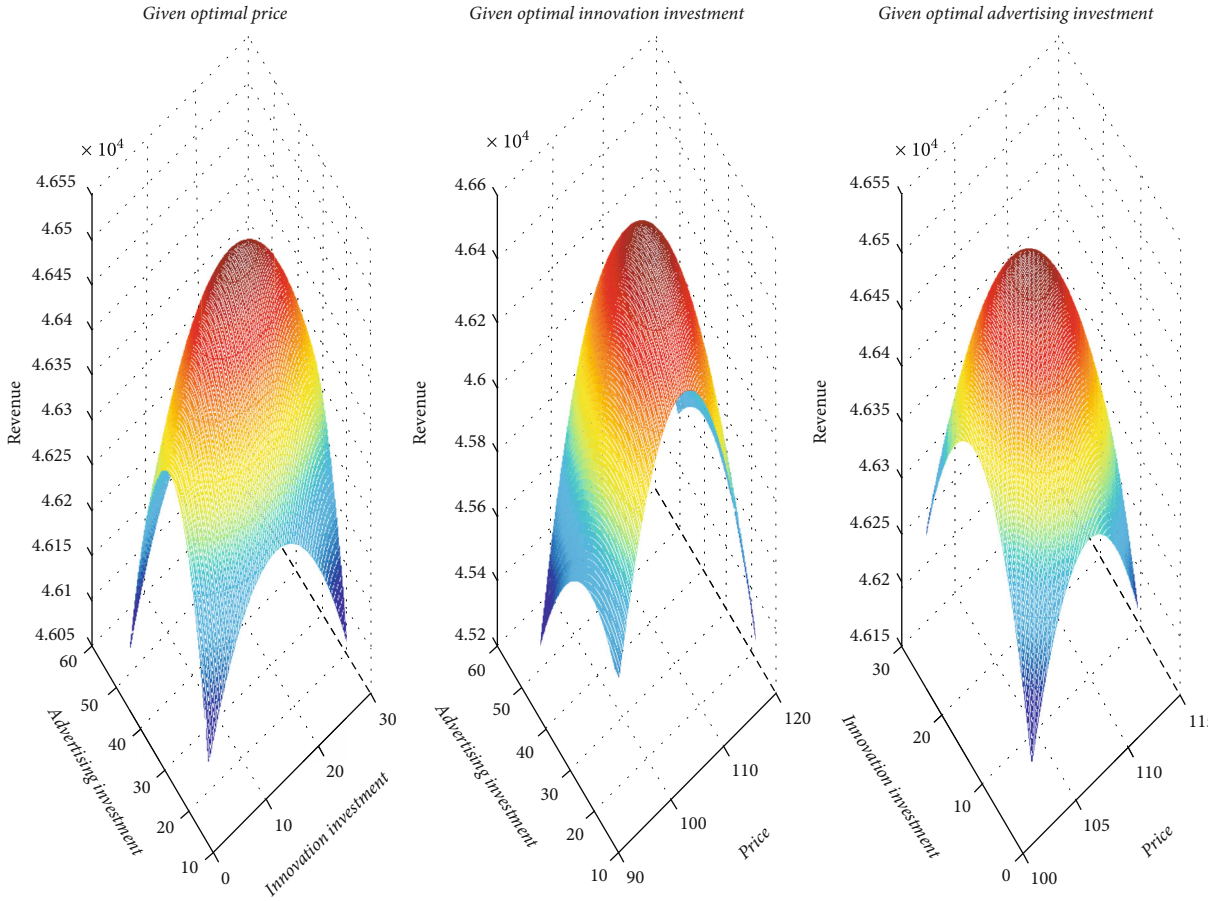

Figure 4: Revenue curves under a hybrid strategy given one variable.

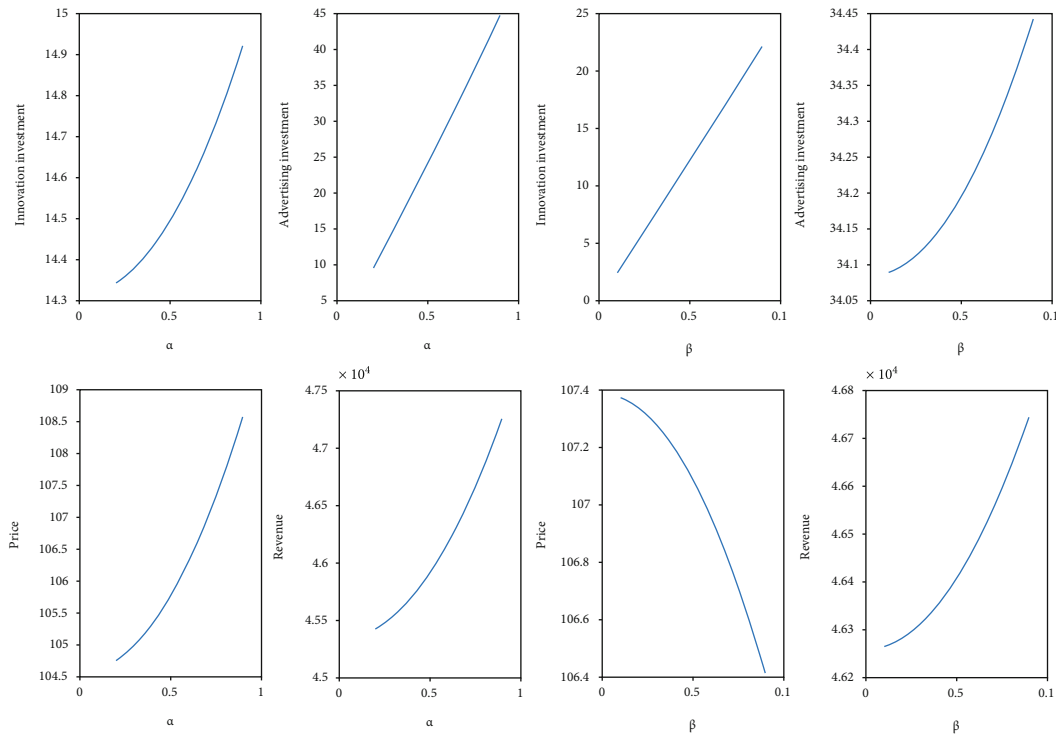

Figure 5: Effects of sensitive coefficients in a supply chain alliance under a hybrid strategy.

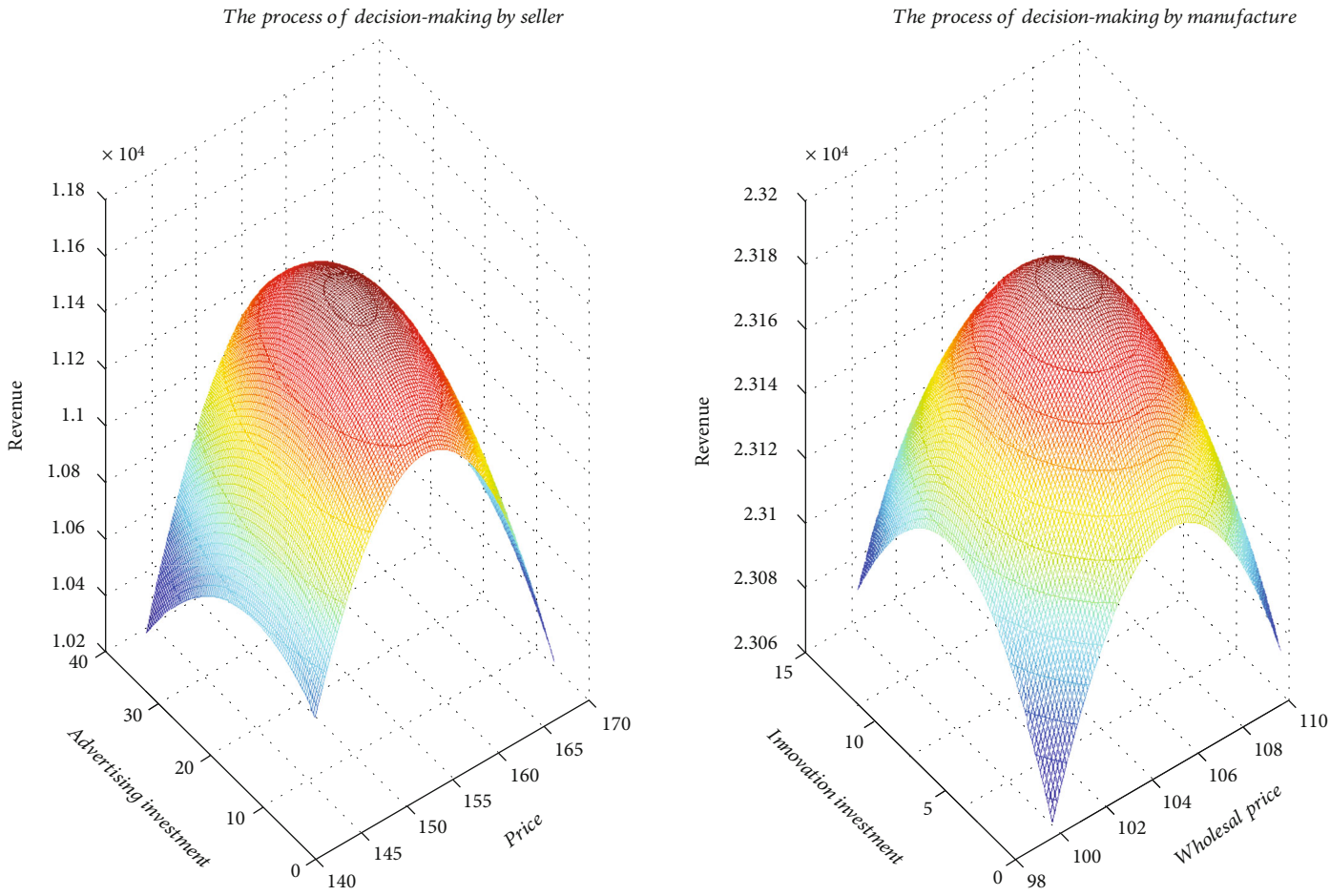

Figure 6: Decision-making processes of a seller and manufacturer under a hybrid strategy.

decentralized system but less than those in a pure center investment strategy. Innovation and advertising investments are both less that than those in a pure strategy if the initiator's promised proportion satisfies

$$t \geq \max\left(1/2, \alpha^2/4k, \left(8k + \beta^2k^2 - \alpha^2 - A\right)/16k\right), \text{ and}$$
$$A = \sqrt{-32\beta^2k^3 + \left(\alpha^2 - k\left(8 + \beta^2k\right)\right)^2}. \quad (17)$$

Proposition 12 suggests that actors in the supply chain alliance will reduce their investments under their full responsibility under hybrid strategy. The initiator's promised proportion can stimulate the follower to invest more investments than those in hybrid with its responsibility.

These theorems and propositions show that a supply chain alliance can be obtained but cannot be balanced in some scenarios. Although investments under various strategies can be compared analytically, it is difficult to analytically compare some decisions, such as those pertaining to profits and retail prices, in various investment strategies due to complexity. Hence, we will employ numerical analysis to demonstrate the decision-making processes.

4. Numerical Analysis

Before performing the numerical analysis, we need to reorganize the constraints among the variables to obtain meaningful conclusions. Statistical big data based on advanced product identification can capture the basic relationships among the variables [36–45]. Subjecting to all constraints being satisfied, it is reasonable to assume the values of some parameters as follows: potential initial market D=1000, original production cost c=10, sensitivity coefficient of market to price k=10, advertising sensitivity coefficient α=0.7, and innovation sensitivity coefficient β=0.065.

4.1. Pure Investment Strategies. In pure investment strategies, the supply chain can make either innovation investments or advertising investments. The revenue curves in pure investment strategies are presented in Figure 1, as follows.

Lemmas 1 and 5 show that supply chains exist with optimal investment decisions in pure innovation and advertising strategies. Propositions 3 and 7 show that the promised proportion has a significant effect on decisions. Figure 2 presents the effects of promised proportions on decisions (e.g., retail price, innovation investment, market sales, wholesale price, revenue) in a pure innovation strategy.

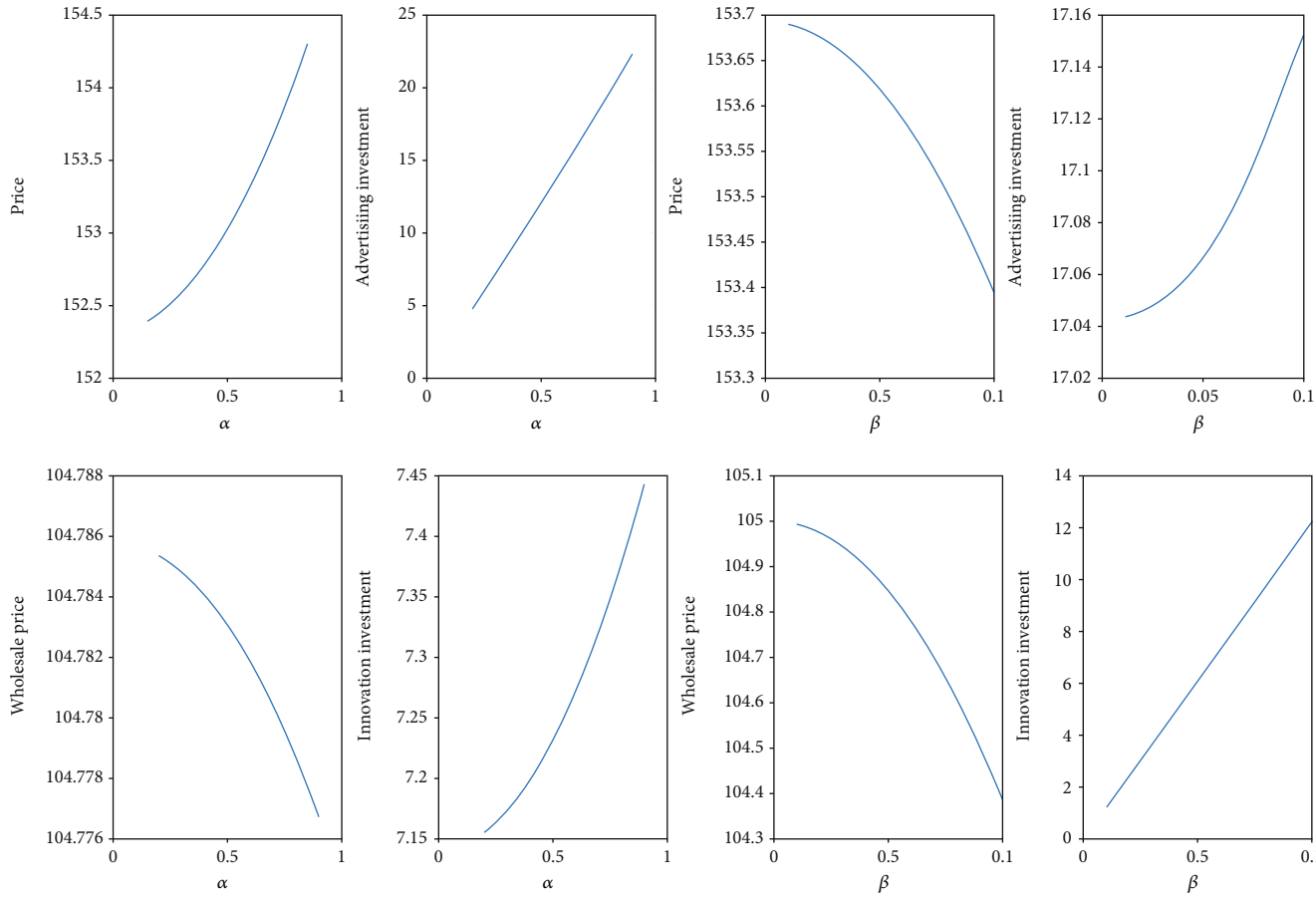

Figure 7: Effects of sensitive coefficients on decentralized decisions under a hybrid strategy.

The total innovation (follower made) increases with the promised proportion increase. Innovation investment reduces the reproduction cost and then decreases the wholesale price, which decrease the retail price and increases market sales. Hence, the promised proportion can stimulate the follower to complete the mission in the supply chain. The manufacturer can transform the profits from innovation investment to the seller with low wholesale prices. The seller can then decrease the retail price to enhance market competitiveness, which is the original intention of the initiator in building a supply chain alliance. However, a high promised proportion increases the manufacturer's revenue but undoubtedly increases the seller's costs and ultimately reduces the seller's revenues.

Similarly, Figure 3 shows the effects of promised proportion on decisions under a pure advertising strategy.

Advertising investment increases with the promised proportion increase. Advertising investment aims to stimulate market sales, but it also means additional costs for both the follower and the initiator. Then, the additional cost causes both the retail price and the wholesale price to increase. Then, market sales will increase for a short period and then drop rapidly. A pure advertising strategy could thus damage both actors' revenues.

4.2. Hybrid Investment Strategies. Figure 4 shows the revenues in the supply chain decision-making process under a hybrid strategy. Then, Figure 5 presents the effects of sensitive coefficients on optimal decisions.

Figure 5 indicates that whichever sensitive coefficient increases, innovation investment, advertising investment, and supply chain alliance revenue all increase. Intuitively, the higher the sensitivity coefficient (i.e., the higher the investment benefit), the greater the investment. This phenomenon reflects the fact that decision-making in a supply chain alliance emphasizes balance between upstream and downstream investment. This balance certainly aims to improve performance. Similar to a pure investment strategy, the advertising effect leads to a high retail price, while the innovation effect reduces the retail price via reducing the reproduction cost. However, it should be emphasized that increasing adverting investment can improve performance, which may be the main difference between the hybrid strategy and the pure strategy. The main reasons may be found in the linkage effect and balance effect in the supply chain alliance.

Figure 6 presents two players' decision-making processes in a decentralized supply chain.

To investigate the effects of sensitive coefficients on equilibrium, Figure 7 presents the optimal decisions (i.e., investment, retail price, and wholesale price changes) with sensitive coefficients (i.e., α, β).

Similarly, whichever sensitive coefficient increases, the investments made by different individual actors also crease. A linkage effect still exists in the decentralized decision-making, even though there is no cross-investment. Even in a decentralized supply chain, the manufacturer will increase

innovation when the sensitive coefficients of innovation increase and then reduce the wholesale price and finally stimulate the seller to lower the retail price. The seller also increases the advertising investment when the sensitive coefficient of advertising increases but still increases the retail price, even when the manufacturer decreases the wholesale price. The reason could be that opportunism exists in the downstream based on the advantage of being close to the market.

Promised proportion is an effective approach for building a supply chain alliance, but it has different effects on decisions under different pure investment strategies. An innovation investment strategy can transform benefits to the downstream, while an advertising investment strategy may have the opposite effect. Although these effects can be improved under a hybrid strategy, opportunism might also arise.

5. Conclusion

In order to cope with rigid environment regulations, manufacturing forms can initiates closed-loop supply chain alliances through suitable partners to focus on product recovery management and even to enjoy the economic benefits. However, an effective closed loop supply chain can simultaneously consider innovation investment in the upstream and advertising investment in the downstream to enjoy the economic benefits. Unlike the current closed-loop supply chain studies with one-way input decisions, this study consider the optimal investment allocation on/between the advertising and innovation within a closed-loop supply chain system, which can be initiated by an initiator's promised proportion in investment. The closed-loop supply chain alliance can be initiated by an initiator's promised proportion in investment. Two ways of building a closed-loop supply chain alliance were considered in this study: the manufacturer initiates or the retailer initiates. A manufacturer initiates a supply chain alliance by promising a proportion of the advertising investment, while the seller promises a proportion of the innovation investment. The equilibriums under various strategies were considered analytically, and some sensitivities of decisions were investigated using numerical analysis.

The results showed that under a pure investment strategy, a promised proportion has a significant effect on investment decisions and can make the supply chain achieve equilibrium. However, a reasonable promised proportion can coordinate the supply chain under a pure innovation strategy but not under a pure advertising strategy. Compared to pure investment, the supply chain center will decrease upstream investment but increase downstream investment under a hybrid strategy. Upstream investments always decrease wholesale and retail prices, while downstream investments increase retail and wholesale prices. Upstream and downstream investments will both increase with a sensitive coefficient increase. Increasing innovation investment can benefit the manufacturer but not the seller, while increasing advertising investment creates costs for both actors under a pure investment strategy. However, increasing innovation or adverting can bring benefits to both actors under a hybrid investment strategy. Generally, the upstream transforms the benefit to the downstream while downstream, not vice versa. The downstream may exhibit opportunism based on the advantage of being close to the market. In summary, a hybrid investment strategy provides insight into optimizing the supply chain system in investments. A supply chain alliance should balance investments in the upstream and downstream simultaneously. The balance between the upstream and downstream can eliminate the negative effect of one-sided investment. Increasing innovation investment in the upstream may be a good choice for the supply chain; after all, it can transfer the benefits to the downstream.

A limitation of this study is that the models only considered operational innovation and advertising investment. There are additional investment choices that could potentially provide mutual benefit. More investment choices could be considered in future work. Moreover, the stochastic of corresponding output with investment could affect investment decisions. How the stochastic of the investment affects the investment decision could also be an interesting direction for future work.

Data Availability

All data are in the article.

Conflicts of Interest

The authors have declared that no competing interests exist concerning this study.

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Supplementary Materials

Supplementary Materials: proofs of lemmas, propositions, and theorems. *(Supplementary Materials)*

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