QUICK RESPONSE IN FAST FASHION OMNICHANNEL: EXPLORING COST SHARING EFFECT

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Abstract. Facing the rapid value decline issue in the fast fashion product (FFP) industry, improving quick response (QR) capability will allow a FFP supply chain to deliver products to customers faster and capture more value. On this basis, the value compensate through QR effort and the coordination strategy for a FFP supply chain in an omnichannel context is investigated. Characterizing the regularity of product value attenuation and also QR effort as the key decision variable in a FFP omnichannel, five differential game theoretical decision models are formulated, solved and compared, including: (i) without cost sharing model under a decentralized decision; (ii) manufacturer-led unilateral cost sharing model under a decentralized decision; (iii) retailer-led unilateral cost sharing model under a decentralized decision; (iv) bilateral cost sharing under a decentralized decision; (v) bilateral cost sharing model under a coordination decision. The corresponding numerical and sensitivity analyses are conducted on a calibrated real-world fast fashion product, and have found that, in order to achieve higher total profit, a cost sharing contract mechanism is better than a without cost sharing contract mechanism; a bilateral mechanism is better than a unilateral mechanism; and a coordination mechanism is better than a decentralized mechanism. The theoretical themes developed in this study imply that FFP omnichannel practitioners should put more resource and energy in coordinating their QR efforts in the supply chain. Importantly, they should collaborate closely to confine the cost of QR effort investment through a smart selection of the right QR technologies and a better utilization of these technologies to develop and support a highly sense-and-respond supply chain operation method.

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1. Introduction

With the rising of per capita disposable income in the emerging economies and the consumption impetus brought by digitalization, a new era of digital consumption has evolved. The dimension of consumption is deepening and expanding in scope. Especially for young consumers who have their own ideas and pursue fashion, their pursuit of new products is significantly accelerating, and this new consumption trend reflects

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consumers’ aspiration for a better life experience and emotional value. In response to the emergence of this new consumption trend, fast fashion brands respond quickly to fashion information by constantly speeding up the update of new products to meet consumers’ increasingly demand. However, in the actual production and operation, due to the endless new products, the life cycle of fast fashion products is drastically shortened, and has a problem that the fashion value of each product decreases rapidly over time. Products that cannot be sold in time will generate huge fashion value loss and have to be liquidated with big discounts at the end of sales, which brings negative financial impact to fast fashion brands. This feature of FFP requires fast fashion brands to build a quick responsive supply chain and improve the responsiveness of each supply chain member in production, transportation, sales, etc. to slow down the decay of the FFP value and compensate for the loss of profit caused by the value decay. In this paper, the measures taken to participate in building the QR process of the supply chain are collectively referred to as QR effort. If too little QR effort is invested, it will be difficult to achieve the expected results; if too much QR effort is invested, it will result in wasteful and redundant resource. Therefore, in order to achieve the optimal performance of the supply chain and its members, it is crucial to explore the optimal QR effort level that need to be invested by each member.

Under the new retail trend, many FFP retailers are embracing the omnichannel strategy to take advantage of the product experiencing from the offline channel and anywhere/anytime purchasing power from the online channel to fully meet market demand. For instance, ZARA’s new concept store in the UK uses the advanced automation technology to boost efficiency. By using fully automated order collection function and self-checkout function, customers can place orders or buy clothes without talking to anyone [3]. In order to meet the increasingly accelerating demand of consumers, online and offline channels should be more integrated and all members in the FFP supply chain should collaborate closely to enhance the QR capability of their supply chain. This is not only imperative but also critical to compete now and in the future.

The differential game method is often used to solve dynamic game problems, which can effectively deal with both the competition and cooperation issues among supply chain members from the perspective of continuous time. For instance, the differential game is widely used in the research of non-instantaneous deteriorating products [1], goodwill and advertising strategies [8, 27, 28, 47], quality control [51–54] and other management fields.

Since the value of the FFP decays overtime and is a special kind of non-instantaneous deteriorating product, it is suitable to use the differential game approach to explore the FFP supply chain issues. This paper will explore various FFP omnichannel supply chain strategies by formulating differential game decision models under different decision scenarios and different cost sharing contracts. Firstly, the decision of supply chain members based on their own optimization is often different from that of the overall optimization of supply chain. According to the different decision objectives, this paper will divide it into decentralized mode and coordinated decision mode. Furthermore, the functions and benefits of the cost sharing contracts have been widely studied and applied in supply chain theory and practice [23, 63, 70]. Since the construction of QR effort requires significant investment from all the supply chain members and is related to their performance, the use of cost sharing contract allows all members to share this cost together and promotes members to reach the optimal QR effort level. At the same time, there are differences in decision dominance among supply chain members in practical operations, so this paper divides situations where manufacturer and retailer are in different positions in decision making. Generally, the member as the dominant party shares the cost of QR effort proportionally for the other member. Therefore, this paper will explore the function of using cost sharing contract and the effect of coordination mechanism by comparing different scenarios of without/with cost sharing and unilateral/bilateral cost sharing.

The rest of the article is organized as follows. The literatures related to this research will be reviewed in Section 2. The modeling notations and assumptions will be defined in Section 3. Five differential game-theoretical decision models will be formulated and solved in Section 4. In Section 5, take a real-world FFP supply chain as an example, the corresponding numerical and sensitivity analyses will be conducted. The managerial insights of this study will be derived and summarized in Section 6. Finally, Section 7 will conclude this research.
2. Literature review

2.1. Omnichannel supply chain

When there are multiple channels in an enterprise, the intense competition among channels tends to harm the performance of the enterprise as each channel tries to pursue its own best interests. When channel competition is intense, multiple supply chains need to consider how to adjust pricing and service strategies faster and more effectively. Chen et al. [10] identified pricing strategy as a central issue under O2O mixed channel competition and compared the impact of different power structures on profit. Kong et al. [32] found that pricing and service depend primarily on consumer price sensitivity and used their relationship to reconcile the channel conflict problem in complementary dual-channel operation of O2O closed-loop supply chain. Keyhanian et al. [30] studied the competition within a parallel distribution channels supply chain to analyze the influence of manufacturers’ cost reduction on the behavior of the supply chain. Li et al. [38] studied the situation that manufacturer sell through direct channel and a platform channel to investigate the interaction between manufacturers’ cooperative advertising strategies and platform distribution contract selection. Zhao and Hou [69] showed that an increase in channel substitutability leads to raising the supplier’s willingness to adopt an encroachment strategy.

In order to solve the problem of inefficiency caused by channel competition, many scholars have proposed new strategies to promote a win-win cooperation to enhance the channel integration effect. Many firms have dedicated to establish different types omnichannel supply chains, also attracting extensive attention from the supply chain research community. Gao and Su [22] discussed the impingement of the BOPS (buy-online-and-pick-up-in-store) initiative on offline operations and found that the use of BOPS is not always profitable, while a cross-channel revenue sharing design can effectively reduce channel conflicts. Yang and Zhang [64] studied the impact of “STS (ship-to-store)” program on brand management and QR value. The results showed that although STS is beneficial to enterprises in most cases, the inventory information exposed during STS implementation may lead to a decrease in retailer profit, and the value of QR can also be reduced if customers do not choose STS when they are out of stock. Sarkar and Pal [50] constructed a multi-channel supply chain frameworks with traditional channels and a direct channel to discuss the optimal pricing decisions and services. Karimi et al. [29] investigated service, price, and inventory decisions under retailers’ competition and cooperation. Choi et al. [16] studied how to provide a series of best services to customers through intelligent dual-channel strategy, and examined the centralized cases is better than non-centralized case in performance.

From the above research, it can be seen that an important research direction is to explore the impact of omnichannel strategy on supply chain operation, but there is still no general conclusion. One of our research purposes is to explore the impact of the implementation of omnichannel strategy on FFP supply chain.

2.2. FFP supply chain

An important problem faced by fast fashion retailing is that the value of commodities decreases rapidly with time, resulting in a decline in demand and profit. In response to the non-instantaneous deteriorating characteristic of FFP value, many existing research focus on the pricing and inventory decision issues. Tsao and Sheen [55] studied the dynamic pricing, promotion and replenishment of deteriorating items under the trade credit of supplier and the promotion effort of retailer. Maihami and Kamalabadi [42] and Maihami and Abadi [41] developed a joint pricing and inventory control method for non-instantaneous deteriorating items to maximize profit. Maihami and Karimi [43] considered the replenishment strategy and pricing of non-instantaneous deteriorating items affected by the promotion effort. Zhang et al. [66] studied the optimal dynamic pricing strategy and replenishment cycle for a non-instantaneous deteriorating item. Banerjee and Agrawalwe [1] developed and analyzed an inventory model of a deteriorating item and demand function depending on price and freshness. Li et al. [36] studied the joint pricing, replenishment and preservation technology investment of non-instantaneous deteriorating items. Chen [9] proposed a new decision-making problem of perishable products inventory with pricing and promotion of a single supplier multi-buyer system.
Many scholars have tried to solve the problems arising in FFP supply chain operations from different perspectives. Choi et al. [15] developed an intelligent prediction algorithm that conforms to the fast fashion demand patterns. Li et al. [35] examined the impact of corporate social responsibility behavior on sustainable performance in fast fashion supply chain, developed a sustainable governance mechanism framework and concluded that enterprises need to strengthen their core CSR position. Wen et al. [61] reviewed and summarized the operational research literature of each functional area of fashion retail supply chain. Choi and Liu [14] studied the optimal allocation strategy of advertising budget in multi-brand luxury fashion supply chain and explored the optimal strategy by designing coordination mechanism to overcome polarization. Wei and Li [60] studied the impact on consumer behavior and company management decision in terms of valuation and channel selection under the strategic background of omnichannel luxury retailing. Zhao et al. [71] investigated different situations in which a revenue sharing contract and a linear quantity discount contract can coordinate in a fashion supply chain with interrupted demand. Duan and Cao [19] studied the joint dynamic pricing and deteriorating inventory management problem in the presence of reference price and stock display effects, and found that current reference price level has a positive effect while inventory level has a negative on the optimal replenishment rate and price.

Although the existing research has put forward some corresponding solutions to the problems caused by FFP value attenuation, the original feature has not been improved. QR is closely related to the value of FFP, and we try to compensate for the value loss of FFP from the perspective of QR in our research.

2.3. QR in supply chain

Many scholars have studied the influence of building QR on the supply chain. Lin and Parlaktürk [39] studied the impact of QR and competition on the manufacturer and retailers in a business channel by comparing the ordering and pricing decisions of two competing retailers under three conditions of whether they have QR ability. Li [37] studied the relationship between pressure, practice and performance of green supply chain management under the moderating effect of QR regulation.

Some contracts are used in QR system to seek profit optimization. Yang et al. [65] studied the pricing and inventory decisions in the decentralized and centralized scenarios with revenue sharing contract and compared the value created by QR in different supply chain structures. Krishnan et al. [33] looking at the potentially destructive impact of QR on retailer concluded that simple distribution contracts can make up for the distorted QR impact on retailer effort.

The influencing factors of QR were also explored in research. Choi et al. [13] considered the impact of retailers’ random risk preference on the QR value of the supply chain and its members. The study found that QR is beneficial to the supply chain sensitive to random risks and robust Pareto improvement can be realized by using contracts. Wang et al. [59] discussed the influence of different customer types and whether a QR strategy affects retailers’ optimal inventory and pricing decisions. Zhang et al. [68] studied QR implementation in a two-level supply chain with Bayesian demand information updating and the impact of uncertain production capacity on supply chain ordering strategy.

From the above literature, it is not difficult to find that the improvement of QR has a significant impact on supply chain performance, and there are many factors that affect QR level. At the same time, the design of contract has played a role in the performance optimization of supply chain. Based on these experiences, we explore the influence of QR on supply chain performance and the effect of contract application.

2.4. QR in FFP supply chain

Scholars have studied the value of QR in the FFP supply chain. Cachon and Swinney [4] combined QR with design capabilities in a FFP supply chain system to achieve high profit with participation of strategic customers. Choi [13] discovered that the possibility of social media’s good comments on products plays a crucial role in influencing the value of QR.
The application of QR has brought many benefits to the FFP supply chain. Kim [31] proposed an analytical profit maximization model in a clothing QR supply chain to solve the imbalance between supply and demand, and discussed how to use a variety of supply options to improve suppliers’ potential competitive advantages. Choi [11] revealed the influence of retailers’ risk aversion behavior on the FFP supply chain system that uses QR to reduce demand uncertainty.

The use of appropriate contracts will optimize the benefits of a quick responsive FFP supply chain. Donohue [18] studied how to make contracts in the two modes of product environment to promote the coordination of manufacturer and distributor of FFP supply chain in forecasting information and production decisions. Fisher et al. [21] designed a two-stage stochastic dynamic model to decide the optimal reorder time and the best replenishment contract of a short lifetime FFP. Choi [12] studied the impact on the profits of fashion retail supply chain resulted from the inventory service target QR program and designed three contracts to achieve win-win results. Choi [13] found that under the surplus sharing contract, manipulating social media reviews will benefit manufacturer.

The literature review has shown that even though rich research existed regarding the FFP supply chain, but how QR effort affect the performance of a FFP omnichannel supply chain with a non-instantaneous deteriorating nature is still absent. This paper will explore further into this subject to gain more theoretical understanding and practical insights.

3. Modeling notations and assumptions

Consider a stylized FFP omnichannel supply chain system composed by a manufacturer and a retailer. In this system, FFP is produced by a manufacturer and then sold to consumers through omnichannel built by a retailer. Consumers play an important role to drive the FFP supply chain to improve the QR effort level. In order to ensure consumers’ satisfaction with the products and service they purchase and to expand the supply chain performance, both the manufacturer and the retailer have to integrate the manufacturing and selling processes to enhance QR capability. Specifically, the retailer needs to collect fashion and sales information, then feed them back fast to the manufacturer. After receiving these information, the manufacturer should develop and operate an effective and speedy production and distribution system to support the retailer in meeting the consumer’s demand. Retailer should arrange the marketing and advertising as soon as possible after received products from the manufacturer. Overall, all members of the supply chain should follow the same goal of reducing the time from production to customer consumption.

The FFP omnichannel supply chain system differs from the typical dual channels that separate the online and offline selling channels, rather it includes an integration mechanism between the online and offline sales channels. The retailer’s online channel can provide consumers with more product information 24/7, making consumers easier to compare with other similar products. Distributing to the consumers’ doors also saves the physical shopping time. At the same time, the offline channel provides a physical place for consumers to try out products and experience service. Consumers will gain direct insights regarding the products and brands after experiencing them in person, and this will facilitate their buying decisions. The omnichannel mode can effectively avoid competition between channels and fully combine to leverage the advantages of online and offline channels to expand consumer demand and achieve higher performance.

For the modeling purpose, all notations and definitions of parameters in different functions used in the differential game models are shown in Table 1. Key parameters and its meanings in the models will be introduced next.

According to Krishnan [34], QR effort has an impact on both supply and demand, not only on the value decay rate, but also on the demand function. Following Nerlove and Arrow [44], Jorgensen et al. [27] and Wang and Li [58], the differential equation of time-varying value can be given as:

$$\dot{V}(t) = mE_M(t) + nE_R(t) - \theta V(t)$$
Table 1. Parameter notations and definitions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>Coefficient of $E_M(t)$ on product’s value</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>Coefficient of $E_R(t)$ on product’s value</td>
<td></td>
</tr>
<tr>
<td>$\theta$</td>
<td>Value decay rate</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Attenuation coefficient</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Attenuation index</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>$t = {1, 2, \ldots, T}$, product life duration (metric: day)</td>
<td></td>
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</tbody>
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Parameters related to cost functions

- $k_m$: Coefficient of $E_M(t)$ on its cost
- $k_r$: Coefficient of $E_R(t)$ on its cost

Parameters related to demand functions

- $\lambda$: Proportion of online channel sales to omnichannel sales
- $\alpha, \beta, \gamma$: Coefficients of $E_M(t), E_R(t), V(t)$ on demand
- $g$: Coefficient of service on demand for online channel
- $h$: Coefficient of service on demand for offline channel
- $\eta$: Coefficient of price on demand
- $p$: Retail price set by retailer
- $S$: Service level provided by retailer
- $k_s$: Coefficient of retailer’s service on its cost
- $C_{on}$: Unit cost of online channel operation
- $C_{off}$: Unit cost of offline channel operation

Parameters related to profit functions

- $w$: Wholesale price set by manufacturer
- $C_m$: Manufacturing cost
- $\rho$: Discount rate

in which, $E_M(t)$ and $E_R(t)$ are the decision variables in the decision models, represent QR efforts offered by manufacturer and retailer respectively. According to Cai et al. [5], the QR efforts in this paper refer to all the kinds of inputs invested to improve the QR level in order to delay the decline of the FFP value in the supply chain. $V(t)$ calculates the value of FFP at time $t$. $\theta$ is the decay rate of the time-varying value, following Blackburn and Scudder [2], it can be given by:

$$\theta = A(e^{Bt} - 1), \quad A > 0, \quad B > 0.$$  

The higher the degree of QR effort, the higher the cost to support it. For this reason, the cost functions of QR efforts of the manufacturer and retailer are convex. According to Liu et al. [40], the cost of the manufacturer’s QR effort can be expressed by the formula:

$$C_{EM}(t) = \frac{1}{2} k_m E_M^2(t).$$

Similarly, the cost of the retailer’s QR effort can be formulated as:

$$C_{ER}(t) = \frac{1}{2} k_r E_R^2(t).$$

Referring to Jorgensen et al. [27], the demand of products sold in the online channel can be calculated as:

$$D_{on}(t) = \lambda[\alpha E_M(t) + \beta E_R(t) + \gamma V(t)] + gS(t) - \eta p(t)$$
Table 2. Distinction of five decision models.

<table>
<thead>
<tr>
<th>Model #</th>
<th>Sub-section</th>
<th>Decision type</th>
<th>Cost sharing contract?</th>
<th>Cost sharing coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Decentralized</td>
<td>Coordination</td>
<td>Without</td>
</tr>
<tr>
<td>1</td>
<td>4.1</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>4.2.1</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>4.2.2</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>4.3</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>4.4</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

and that sold in the offline channel as:

\[ D_{\text{off}}(t) = (1 - \lambda)[\alpha E_M(t) + \beta E_R(t) + \gamma V(t)] + hS(t) - \eta p(t). \]

The total demand of the entire omnichannel is the sum of the demand for the online and offline channels, which can be expressed as:

\[ D(t) = D_{\text{on}}(t) + D_{\text{off}}(t) = \alpha E_M(t) + \beta E_R(t) + \gamma V(t) + (g + h)S(t) - 2\eta p(t). \]

The service provided by the offline stores often give customers a unique experience that may contribute to both online and offline demands. Based on the study of Xu et al. [62], a convex function is suitable for describing the service cost. This research uses \( S(t) \) to indicate the service level provided by offline stores and the service cost incurred is represented by \( C_S = \frac{1}{2}k_S S^2(t) \).

4. Formulating differential game theoretical decision models

The QR effort of a FFP supply chain and the attenuation of its product value are changing dynamically with time \( t \). When improving QR capability, putting into not enough effort, i.e., investment, the QR ability cannot be enhanced to the competitive level; however, putting into too much effort will lead to unexpected high cost causing lower ROI (return on investment). This section will develop the differential game decision models with HJB equations (Hamilton–Jacoby–Bellman equations, [17]) to explore the optimal QR effort level such that FFP can be sold at the time while its value is still high to maximize the supply chain profit.

According to the different decision modes, dominant parties and cost sharing types, there are different decision scenarios as follows: (1) no dominant party and no cost sharing under decentralized decision mode; (2) the manufacturer is the dominant party under decentralized decision mode and provides unilateral cost sharing proportion \( \phi \) for the retailer; (3) the retailer is the dominant party under decentralized decision mode and provides unilateral cost sharing proportion \( \xi \) for the manufacturer; (4) no dominant party under decentralized decision mode and the manufacturer and the retailer provide bilateral cost sharing coefficients \( \phi \) and \( \xi \) for each other; (5) no dominant party under coordinated decision mode and the manufacturer and the retailer provide bilateral cost sharing coefficients \( \phi \) and \( \xi \) for each other. The advantage of sharing QR effort costs in the supply chain is that it can reduce the financial burden of the supply chain members and encourage them to jointly improve the QR level. The optimal proportion of \( \phi \) and \( \xi \) will be determined in the decision models.

In Table 2, the five decision models can be distinguished by the decision type, the cost sharing contract and the cost sharing coefficient. “✓” symbol indicates that the model has the characteristics while “x” symbol indicates the opposite. The formulation of the five differential decision models and their optimization derivations will be followed.

4.1. Model without cost sharing under decentralized decision

Without cost sharing, the manufacturer and retailer are on the same decision place, they follow the optimal strategy of a static Nash equilibrium, decide their own optimal QR efforts simultaneously to maximize their
own profits. In this model, the objective functions of the manufacturer and retailer can be written as:

\[ J_M = \int_0^T e^{-pt}[(w - C_m)D(t) - C_{E_M}(t)] \, dt, \]  
\[ J_R = \int_0^T e^{-pt}[(p - w)D(t) - C_{E_R}(t) - C_{on}D_{on}(t) - C_{off}D_{off}(t) - C_S] \, dt. \]  

To simplify the formula expression, we use \( C_1 \) to represent \( \lambda C_{on} + (1 - \lambda)C_{off} \) and \( C_2 \) to represent \( (gS - \eta p)C_{on} + (hS - \eta p)C_{off} \). After calculation, the optimal efforts of the manufacturer and retailer in this model are:

\[ E_{M}^{*} = \frac{[\alpha(p + \theta) + m\gamma](w - C_m)}{k_m(p + \theta)}, \quad E_{R}^{*} = \frac{[\beta(p + \theta) + n\gamma](p - w - C_1)}{k_r(p + \theta)}. \]

Furthermore, we can get the optimal profits of the manufacturer and retailer as follows:

\[ \Pi_{M}^{*} = \frac{[\alpha(p + \theta) + m\gamma]^2(w - C_m)^2}{2k_m\rho(p + \theta)^2} + \frac{[\beta(p + \theta) + n\gamma]^2(w - C_m)(p - w - C_1)}{k_r\rho(p + \theta)^2} \]
\[ + \frac{[(g + h)S - 2\eta p](w - C_m)}{\rho} + \frac{\gamma(w - C_m)}{\rho}V, \]
\[ \Pi_{R}^{*} = \frac{[\alpha(p + \theta) + m\gamma]^2(w - C_m)(p - w - C_1)}{2k_m\rho(p + \theta)^2} + \frac{[\beta(p + \theta) + n\gamma]^2(p - w - C_1)^2}{2k_r\rho(p + \theta)^2} \]
\[ + \frac{[(g + h)S - 2\eta p](p - w) - C_2}{\rho} - \frac{k_sS^2}{2\rho} + \frac{\gamma(p - w - C_1)}{\rho}V. \]

### 4.2. Models with unilateral cost sharing under decentralized decision

When one of the manufacturer or retailer is in the dominant position and the other is in the subordinate position, the two members will play a Stackelberg game. In this section, the manufacturer as the leader and the retailer as the leader are formulated into two decision models separately. The leader of the FFP supply chain determines a cost sharing coefficient for the follower.

#### 4.2.1. Model with unilateral cost sharing dominated by manufacturer

When the manufacturer of FFP is the leader and the retailer is the follower, the manufacturer will share a portion of the cost of the retailer’s QR effort to encourage the retailer to improve the level of its QR effort. The manufacturer first decides its own optimal QR effort level and the cost sharing coefficient \( \phi \) for the retailer. After observing the manufacturer’s decision, the retailer decides its optimal QR effort level according to the principle of maximizing its own profit.

According to the backward induction method, the retailer’s optimal QR effort level needs to be first determined. The manufacturer will decide its own optimal effort level and the cost sharing coefficient depends on the retailer’s optimal effort level. The manufacturer’s and the retailer’s objective functions can be written as follows:

\[ J_M = \int_0^T e^{-pt}[(w - C_m)D - \phi C_{E_R} - C_{E_M}] \, dt, \]  
\[ J_R = \int_0^T e^{-pt}[(p - w)D - (1 - \phi)C_{E_R} - C_{on}D_{on} - C_{off}D_{off} - C_S] \, dt. \]  

After solving the optimal effort levels of the manufacturer and retailer, we will get the optimal effort of the manufacturer and retailer, and the optimal cost sharing coefficient as:

\[ E_{M}^{*} = \frac{[\alpha(p + \theta) + m\gamma](w - C_m)}{k_m(p + \theta)}, \]
The optimal profits of the manufacturer and retailer are:

\[ E^*_R = \frac{[\beta(\rho + \theta) + n\gamma](p - w - C_1)}{(1 - \phi^*_m)k_r(\rho + \theta)}, \]

\[ \phi^*_m = \frac{3w - p - 2C_m + C_1}{w + p - 2C_m - C_1}. \]  

Similarly, to simplify the expression, we use \( C_2 \) to represent \((gS - \eta p)C_{on} + (hS - \eta p)C_{off}\). Under this situation, the optimal profits of the manufacturer and retailer are:

\[ \Pi^*_M = \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2k_m}(\rho + \theta)^2 + \frac{\phi^*_m[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{(1 - \phi^*_m)k_r(\rho + \theta)^2} - \frac{\phi^*_m[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{2(1 - \phi^*_m)k_r(\rho + \theta)^2} + \frac{(p - w)[(g + h)S - 2\eta p] - C_2}{\rho} \]

\[ + \frac{k_sS^2}{2\rho} + \frac{\gamma(p - w - C_1)}{\rho + \theta}V. \]  

\[ \Pi^*_R = \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2k_m}(\rho + \theta)^2 + \frac{\phi^*_m[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{(1 - \phi^*_m)k_r(\rho + \theta)^2} - \frac{\phi^*_m[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{2(1 - \phi^*_m)k_r(\rho + \theta)^2} + \frac{(p - w)[(g + h)S - 2\eta p] - C_2}{\rho} \]

\[ + \frac{k_sS^2}{2\rho} + \frac{\gamma(p - w - C_1)}{\rho + \theta}V. \]  

4.2.2. Model with unilateral cost sharing dominated by retailer

Contrary to the situation in 4.2.1, the retailer now is the leader while the manufacturer is the follower. The retailer will provide a cost sharing to the manufacturer’s QR effort cost to encourage the manufacturer to improve its QR effort level. The decision sequence is as follows: the retailer will first decide its own QR effort level and a cost sharing coefficient \( \xi \), then the manufacturer decides its QR effort level. The manufacturer’s and retailer’s objective functions can now be obtained as follows:

\[ J_M = \int_0^T e^{-\rho t}[(w - C_m)D - (1 - \xi)C_{E_M}] \, dt, \]  

\[ J_R = \int_0^T e^{-\rho t}[(p - w)D - C_{E_R} - \xi C_{E_M} - C_{on}D_{on} - C_{off}D_{off} - C_S] \, dt. \]  

Under this scenario, the optimal QR effort levels of the manufacturer and retailer, the cost sharing coefficient of the retailer and the optimal profits of the manufacturer and retailer can be derived as:

\[ E^*_M = \frac{[\alpha(\rho + \theta) + m\gamma](w - C_m)}{(1 - \xi^*_r)k_m(\rho + \theta)}, \]

\[ E^*_R = \frac{[\beta(\rho + \theta) + n\gamma](p - w - C_1)}{k_r(\rho + \theta)}, \]

\[ \xi^*_r = \frac{2p - 3w - 2C_1 + C_m}{2p - w - 2C_1 - C_m}, \]  

\[ \Pi^*_M = \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2k_m}(\rho + \theta)^2 + \frac{[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{k_r(\rho + \theta)^2} + \frac{(w - C_m)[(g + h)S - 2\eta p] - C_2}{\rho} + \frac{\gamma(w - C_m)V}{\rho + \theta}, \]

\[ \Pi^*_R = \frac{[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{2k_r(\rho + \theta)^2} + \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)(p - w - C_1)}{(1 - \xi^*_r)k_m(\rho + \theta)^2} \]

\[ - \frac{\xi^*_r[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2(1 - \xi^*_r)k_m(\rho + \theta)^2} + \frac{(p - w)[(g + h)S - 2\eta p] - C_2}{\rho} - \frac{k_sS^2}{2\rho} + \frac{\gamma(p - w - C_1)}{\rho + \theta}V. \]  

\[ (15) \]
4.3. Model with bilateral cost sharing under decentralized decision

In order to further stimulate both the manufacturer and retailer to make efforts to improve their QR ability, this model uses a bilateral cost sharing contract, in which the manufacturer and retailer provide each other with a cost sharing proportion for their QR efforts. Under this mechanism, the manufacturer and retailer share the costs of their QR effort with each other to form a fairer and beneficial game. The manufacturer will share the retailer's cost of QR effort with a sharing coefficient $\phi$. At the same time, the retailer will also share the manufacturer's cost of QR effort with a sharing coefficient $\xi$. In this model, the manufacturer and retailer make these decisions simultaneously. They will first decide their own optimal QR efforts and then decide the optimal cost sharing coefficients for each other. Their objective functions are:

$$J_M = \int_0^T e^{-\rho t}[(w - C_m)D - (1 - \xi)C_{EM} - \phi C_{ER}] \, dt,$$

$$J_R = \int_0^T e^{-\rho t}[(p - w)D - (1 - \phi)C_{ER} - \xi C_{EM} - C_{on}D_{on} - C_{off}D_{off} - C_S] \, dt.$$  

By calculating the first partial derivative solution of the above two equations, the optimal effort levels and the optimal sharing coefficients are:

$$E_{M}^{b*} = \frac{[\alpha(\rho + m\gamma)](w - C_m)}{(1 - \xi_k)k_m(\rho + \theta)},$$

$$E_{R}^{b*} = \frac{[\beta(\rho + \theta) + n\gamma](p - w - C_1)}{(1 - \phi_k)k_r(\rho + \theta)},$$

$$\phi_k^* = \frac{3w - p - 2C_m + C_1}{w + p - 2C_m - C_1},$$

$$\xi_k^* = \frac{2p - 3w - 2C_1 + C_m}{2p - w - 2C_1 - C_m}.$$  

According to equations (18) and (19), the optimal profits of the manufacturer and retailer in this model are derived as follows:

$$\Pi_{M}^{b*} = \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2(1 - \xi_k)^2k_m(\rho + \theta)^2} + \frac{[\beta(\rho + \theta) + n\gamma]^2(w - C_m)(p - w - C_1)}{(1 - \phi_k)^2k_r(\rho + \theta)^2} - \frac{\phi_k^*[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{2(1 - \phi_k)^2k_r(\rho + \theta)^2} + \frac{(w - C_M)[(g + h)S - 2\eta p]}{\rho} + \frac{\gamma(w - C_m)}{\rho + \theta},$$

$$\Pi_{R}^{b*} = \frac{[\beta(\rho + \theta) + n\gamma]^2(p - w - C_1)^2}{2(1 - \phi_k)^2k_r(\rho + \theta)^2} + \frac{[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)(p - w - C_1)}{(1 - \xi_k)^2k_m(\rho + \theta)^2} - \frac{\xi_k^*[\alpha(\rho + \theta) + m\gamma]^2(w - C_m)^2}{2(1 - \xi_k)^2k_m(\rho + \theta)^2} + \frac{(p - w)[(g + h)S - 2\eta p] - C_2}{\rho} - \frac{k_sS^2}{2p} + \frac{\gamma(p - w - C_1)}{\rho + \theta}.$$  

4.4. Model with bilateral cost sharing under coordination decision

Coordination decision work on the basis of achieving centralized highest profit of the supply chain. To achieve the highest total profit, the manufacturer and retailer jointly determine the optimal levels of the QR effort. In order to maximize the overall revenue of the supply chain, the objective function of the total profit of the supply chain in HJB equation are:

$$J_C = \int_0^T e^{-\rho t}[(w - C_m)D - C_{EM}] + [(p - w)D - C_{ER} - C_{on}D_{on} - C_{off}D_{off} - C_S] \, dt.$$
Based on the above equation, the optimal QR effort levels of the manufacturer and retailer and the total profit of the supply chain are obtained as follows:

\[
E_{M}^{c^*} = \frac{\alpha(\rho + \theta) + m\gamma (p - C_m - C_1)}{k_m(\rho + \theta)},
\]

\[
E_{R}^{c^*} = \frac{\beta(\rho + \theta) + n\gamma (p - C_m - C_1)}{k_r(\rho + \theta)},
\]

\[
\Pi_{SC}^{c^*} = \frac{[(\alpha(\rho + \theta) + m\gamma)(w - C_m)]}{2k_m\rho(\rho + \theta)^2} + \frac{[(\beta(\rho + \theta) + n\gamma)(p - w - C_1)]}{2k_r\rho(\rho + \theta)^2}
+ \frac{[(g + h)S - 2\eta p](p - C_m - C_2)}{\rho} + \frac{\rho}{\rho + \theta}V.
\]  

Equation (24) has achieved the highest optimal profit of the supply chain among all previous models but could not distribute the optimal profit to the manufacturer and retailer. Thus, this section will use a bilateral cost sharing contract to coordinate the optimal QR efforts of the manufacturer and retailer and distribute the optimal profit accordingly. To coordinate the supply chain under a bilateral cost sharing contract, the optimal efforts of the manufacturer and retailer in equation (18) must be equal as shown in equation (24):

\[
\begin{align*}
\frac{\alpha(\rho + \theta) + m\gamma (w - C_m)}{k_m(\rho + \theta)} &= \frac{\alpha(\rho + \theta) + m\gamma (p - C_m - C_1)}{k_m(\rho + \theta)}, \\
\frac{\beta(\rho + \theta) + n\gamma (p - w - C_1)}{k_r(\rho + \theta)} &= \frac{\beta(\rho + \theta) + n\gamma (p - C_m - C_1)}{k_r(\rho + \theta)}.
\end{align*}
\]

The optimal cost sharing coefficients can be calculated as:

\[
\phi_c^* = \frac{w - C_m}{p - C_m - C_1}; \quad \xi_c^* = \frac{p - w - C_1}{p - C_m - C_1}.
\]

After coordination, the optimal effort levels of the manufacturer and retailer are derived as:

\[
E_{M}^{*}(w) = \frac{[(\alpha(\rho + \theta) + m\gamma)(w - C_m)]}{(1 - \xi_c^*)k_m(\rho + \theta)},
\]

\[
E_{R}^{*}(w) = \frac{[(\beta(\rho + \theta) + n\gamma)(p - w - C_1)]}{(1 - \phi_c^*)k_r(\rho + \theta)}.
\]

The optimal profits of the manufacturer and retailer can be calculated as follows:

\[
\Pi_{M}^{*} = \frac{[(\alpha(\rho + \theta) + m\gamma)(w - C_m)^2]}{2(1 - \xi_c^*)k_m\rho(\rho + \theta)^2} + \frac{[(\beta(\rho + \theta) + n\gamma)(p - w - C_1)]}{(1 - \phi_c^*)k_r\rho(\rho + \theta)^2}
- \frac{\phi_c^*[(\beta(\rho + \theta) + n\gamma)^2(p - w - C_1)^2]}{2(1 - \phi_c^*)k_r\rho(\rho + \theta)^2} + \frac{[(w - C_m)(g + h)S - 2\eta p]}{\rho} + \frac{\rho}{\rho + \theta}V,
\]

\[
\Pi_{R}^{*} = \frac{[(\beta(\rho + \theta) + n\gamma)(p - w - C_1)^2]}{2(1 - \phi_c^*)k_r\rho(\rho + \theta)^2} + \frac{[(\alpha(\rho + \theta) + m\gamma)(w - C_m)(p - w - C_1)]}{(1 - \xi_c^*)k_m\rho(\rho + \theta)^2}
- \frac{\xi_c^*[(\alpha(\rho + \theta) + m\gamma)^2(w - C_m)^2]}{2(1 - \xi_c^*)k_m\rho(\rho + \theta)^2}.
\]
\[
\frac{(p - w)(g + h)S - 2np}{\rho} - \frac{kS^2}{2\rho} + \frac{\gamma(p - w - C_1)}{\rho + \theta}V. \tag{29}
\]

5. Numerical and sensitivity analyses

ZARA, as a global large-scale FFP retail chain, has always been at the forefront of the fast fashion industry. ZARA has developed a business mode based on QR with short product life cycle and adjust prices frequently. By fully integrating the supply chains, ZARA has built QR as its core competence. ZARA's QR practice allows it to respond fast to market demand changes and predict better the FFP trends. The QR development in ZARA is benefited from the strength of its efficient distribution system and the ongoing information technology investment in every aspect of its business [56].

For the purpose of the numerical and sensitivity analyses, a representative fast fashion product from ZARA is selected and its relevant parameters data are collected or assumed as shown in Table 3 [3, 26, 46, 48]. Generally, it takes 2–3 weeks for a FFP from design to market, and no more than three months at most [20]. Therefore, this paper assumes that the product life cycle is 90 days, which is divided into three stages: exploration stage, growth stage and decline stage [67]. MATLAB 2018b was used to compute and analyze the change of QR effort, profit and the effect of other parameters to accumulated profit in the 90-day product life cycle.

The initial retail price of the product \( p_0 \) in the above table is based on the retail price in China of a new winter coat of ZARA and converted into 120 USD/unit. According to a study of the relationship among manufacturing cost, wholesale price and retail price of FFP [7], the wholesale price is less than half of the retail price, and the manufacturing cost is less than half of the wholesale price, so in our research \( C_M \) is set at 18 USD/unit and \( w \) at 50 USD/unit. Based on Reagan [48], the online and offline channel costs are about 30% and 28% of the retail price respectively. Considering the retail environment in China and the downward trend of FFP retail price, in our research \( C_{on} \) is set at 24 USD/unit and \( C_{off} \) at 20 USD/unit. In this paper, all the influence coefficients are set to decimals between 0 and 1, and the influence of their changes on performance is further explored in the sensitivity analysis part. Other parameter values are set according to the industry practices and analysis needs.

The numerical study has assumed a 90-day product life cycle typical in the fast fashion cloth industry. According to the attenuation regularity of a FFP, the value of product is assumed to decline by 70% after the end of the 90-day product life cycle and the value attenuation rate is defined as the following exponential function:

\[ \theta = 0.07 \times (e^{0.026t} - 1) \]

According to the sales discounting rule of the fast fashion brand practice, the 90-day product life cycle is divided into three stages, each of which includes 20-day regular sales period and 10-day discount promotion period. Assume that the retail price of the FFP remains unchanged at the same sales period. With the passage of time, FFP gradually goes into recession, and the retail price of FFP is always lower than the previous stage. At the end of the discount period in each stage, the retail price of the regular sales period in the next stage will increase, but the overall trend is still gradually decreasing. The set-up of the regular and discount retail prices and its time relationship with each sales stage are assumed and described in the following equation and Figure 1.

\[
p = \begin{cases} 
120, & 1 \leq t \leq 20, \\
110, & 21 \leq t \leq 30, \\
100, & 51 \leq t \leq 60 \\
90, & 81 \leq t \leq 90 
\end{cases} \text{USD/unit;}
\]

The service level should keep a similar regulation with the FFP retail price. When the product price is high, high-quality service should be provided, and the service level should be reduced correspondingly for the products
sold at low prices. Similarly, the service levels at three stages are assumed and shown in the following $S$ equation and Figure 2:

$$S = \begin{cases} 
600, & 1 \leq t \leq 20, \\
500, & 21 \leq t \leq 30, \\
400, & 31 \leq t \leq 50, \\
500, & 51 \leq t \leq 60, \\
200, & 61 \leq t \leq 80 
\end{cases} \text{USD.}$$

In operational practice, we consider $m$ as manufacturing efficiency, $n$ as marketing efficiency, $\alpha$ as customer satisfaction with the product, $\beta$ as consumers’ purchase desire, $g$ as consumers’ willingness to purchase online after experienced offline store service, $h$ as customer repurchase rate in offline channel, and $\eta$ as price elasticity of demand, that is, the response of demand to price.

5.1. Numerical analysis

5.1.1. QR efforts ($E_M$ and $E_R$)

QR efforts are the decision variables in the formulated models where $E_M$ is decided by the manufacturer and $E_R$ is decided by the retailer. The optimal $E_M$ and $E_R$ in 90-day product life cycle under five models are
Table 3. Parameter values for numerical analysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho )</td>
<td>0.1</td>
<td>( k_s )</td>
<td>0.4</td>
</tr>
<tr>
<td>( m )</td>
<td>0.4</td>
<td>( g )</td>
<td>2</td>
</tr>
<tr>
<td>( n )</td>
<td>0.6</td>
<td>( h )</td>
<td>3</td>
</tr>
<tr>
<td>( k_{rn} )</td>
<td>0.2</td>
<td>( \eta )</td>
<td>0.5</td>
</tr>
<tr>
<td>( k_r )</td>
<td>0.3</td>
<td>( C_{rn} )</td>
<td>18 USD/unit</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>0.5</td>
<td>( w )</td>
<td>50 USD/unit</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.3</td>
<td>( p_0 )</td>
<td>120 USD/unit</td>
</tr>
<tr>
<td>( \beta )</td>
<td>0.4</td>
<td>( C_{on} )</td>
<td>24 USD/unit</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.4</td>
<td>( C_{off} )</td>
<td>20 USD/unit</td>
</tr>
</tbody>
</table>

Figure 3. The QR efforts in 90-day product life cycle. (a) Manufacturer and (b) retailer.

shown in Figure 3. It can be seen that \( E_M \) and \( E_R \) are in a downward trend at each stage. Moreover, the QR efforts invested in each stage of the discount promotion period are less than that in the regular sales period at the same stage. This trend shows that the level of QR efforts will be reduced with the decline of the product value.

In Figure 3 with the manufacturer, \( E_{M1} = E_{M2} \), \( E_{M3} = E_{M4} \); while in Figure 3 with the retailer, \( E_{R1} = E_{R2} = E_{R4} \), i.e., both manufacturer and retailer have two sets of overlapping lines. This discovery can be summarized as follows: when the manufacturer or retailer unilaterally shares the other’s QR effort cost, its own optimal QR effort level is the same as that without the cost sharing scenario in Model 1; On the contrary, for the member whose QR effort cost is shared by the other member, its own optimal QR effort level is the same as that of the bilateral sharing scenario in Model 4. This means that when one member of the supply chain shares the cost of QR effort for another member, it will invest a lower level of optimal QR effort. Conversely, when one member of the supply chain invests QR effort with the help provided by another member, it will choose to invest a higher level of optimal QR effort.

The QR efforts invested by the manufacturer and retailer are both the highest under the coordinated cost sharing contract scenario (Model 5), in other words, Model 5 creates the best synergistic effect for the supply chain members to increase their QR efforts.

5.1.2. Product value \((V(t))\)

Since the total demand formula at time \( t \) is \( D(t) = D_{on}(t) + D_{off}(t) = \alpha E_M(t) + \beta E_R(t) + \gamma V(t) + (g + h)S(t) - 2\eta p(t) \), the product value \( V(t) \) is positively related to the total demand. The daily product values in different models during the 90-day product life cycle are shown in Figure 4. It is obvious that the product values
are rising in the first 20 days, then gradually decline for the rest of the days. At each stage, the product value in the discount promotion period is always lower than that of the regular sales period at the same stage. And it is easy to see from this figure that the later the sales stage, the lower the values of the product compared to the previous stages. Comparing the product value under different models, it shows the product values of Model 5 > Model 4 > Model 1. However, the two models with the unilateral cost sharing (2 and 3), impacted by QR efforts, show that the product values of the retailer-led Model 3 are higher than those of the manufacturer-led Model 2 in 1–50 days, but lower than those of the manufacturer-led Model 2 in 51–90 days. The product values of Model 5 are always higher than those of the other models in the same sales period. Since higher product values create higher demands, in sum, Model 5 has the best performance in terms of the product value and demand creation.

5.1.3. The profits

This section will analyze the daily profits and accumulated profits of the manufacturer, retailer and supply chain in different models during the 90-day product life cycle.

(1) The daily profits

The daily profits of the manufacturer, retailer and supply chain are shown respectively in Figure 5. As shown in the figure, the daily profit plots of the manufacturer and retailer are very similar. Within 0–12 days, the daily profit increases and after that begins to show a downward trend. Comparing each stage, the daily profit of each stage is lower than that of the previous stages, and the profit of the regular sales period is higher than that of the discount period in each stage. Comparing the daily profits of the manufacturer and retailer, the daily
The accumulated profits in 90-day product life cycle. (a) Manufacturer, (b) retailer and (c) supply chain.

profit of the retailer is higher than that of the manufacturer in the first 20 days, and lower than that of the manufacturer thereafter.

The daily profit of the manufacturer and retailer under different models can be ranked as: Model 5 $>$ Model 4 $>$ Model 3 $>$ Model 2 $>$ Model 1. Daily profits in Model 5 are the highest, which demonstrates that Model 5 using the contract coordination can create the highest profits among all models. It can also be observed that the differences in daily profits obtained under all models are larger in the first 50 days of the product life cycle, but they gradually converge to a similar lower level between 51 and 90 days.

(2) The accumulated profits

The accumulated profits of the manufacturer, retailer and supply chain in the 90-day product life cycle are plotted in Figure 6. It shows a growing trend of the accumulated profits but gradually plateaued when reaching the end of product life cycle. This is because the decline of the daily profits leads to the marginal profits decrease in the later period of the product life cycle. After the 60th day, the retailer’s accumulated profit is smaller than that of the manufacturer, which reflects that the decline of the product value has a greater adverse impact on the retailer than that of the manufacturer. Specifically, for manufacture and retailer, the benefits brought by Model 5 are significantly higher than those of the other models. It is shown that Model 5 creates a much larger gap of the accumulated profits among all models as the sales day moves toward the end of the product life cycle.

Table 4 shows the total accumulated profits of the manufacturer, retailer and supply chain under different models. It can be seen that the total profit of the manufacturer is always higher than that of the retailer under all the scenarios. The total profit of each model present the following rankings: Model 5 $>$ Model 4 $>$ Model 3 $>$ Model 2 $>$ Model 1.

In summary, the following phenomenon are observed from Table 4:

(1) Sharing costs in the FFP omnichannel supply chain could create more profit than that without sharing;
(2) Bilateral cost sharing in the FFP omnichannel supply chain could generate more profit than those with only unilateral cost sharing;
(3) Bilateral cost sharing coordination in the FFP omnichannel supply chain is better than that without coordination regarding the profit generation;
(4) Model 5, *i.e.* coordinated with bilateral cost sharing, creates the highest total profit for the manufacturer, retailer and supply chain among all models.

5.1.4. The QR effort cost sharing coefficients

Table 5 provides an analysis of the optimal cost sharing coefficients at different sales periods for each cost sharing model, several valuable insights can be derived from the table.

First, in each sales period, the members under the bilateral coordinated cost sharing scenario are willing to share more QR effort cost of their partners in the supply chain. At the same time, when one member of the

![Figure 6. The accumulated profits in 90-day product life cycle. (a) Manufacturer, (b) retailer and (c) supply chain.](image-url)
Table 4. Total accumulated profit of five models.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Model type</th>
<th>Model 1 (decentralized without cost sharing)</th>
<th>Model 2 (decentralized with cost sharing, retailer-led)</th>
<th>Model 3 (decentralized with cost sharing, manufacturer-led)</th>
<th>Model 4 (decentralized with bilateral cost sharing)</th>
<th>Model 5 (coordinated with bilateral cost sharing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer ($\times 10^7$)</td>
<td>9.2125</td>
<td>9.3972</td>
<td>9.7380</td>
<td>9.9227</td>
<td>10.3640</td>
<td></td>
</tr>
<tr>
<td>Retailer ($\times 10^7$)</td>
<td>7.1654</td>
<td>7.5137</td>
<td>7.7978</td>
<td>8.1461</td>
<td>9.1423</td>
<td></td>
</tr>
<tr>
<td>Supply chain ($\times 10^7$)</td>
<td>16.3780</td>
<td>16.9110</td>
<td>17.5360</td>
<td>18.0690</td>
<td>19.5060</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. The optimal cost sharing coefficients in the cost sharing models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Coeff.</th>
<th>Sales period in the 90-day product life cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sales period in the 90-day product life cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[1,20]</td>
<td>[21,30]</td>
</tr>
<tr>
<td>2</td>
<td>$\phi_m^*$</td>
<td>14.29</td>
</tr>
<tr>
<td>3</td>
<td>$\xi_r^*$</td>
<td>50.00</td>
</tr>
<tr>
<td>4</td>
<td>$\phi_b^*$</td>
<td>14.29</td>
</tr>
<tr>
<td>5</td>
<td>$\xi_b^*$</td>
<td>50.00</td>
</tr>
<tr>
<td>5</td>
<td>$\phi_c^*$</td>
<td>40.00</td>
</tr>
<tr>
<td>5</td>
<td>$\xi_c^*$</td>
<td>60.00</td>
</tr>
</tbody>
</table>

Notes: (1) the metric of cost sharing coefficients is %; (2) model 4 and 5 are bilateral cost sharing models.

supply chain unilaterally shares the cost for another member, both members provide the same proportion as in the bilateral cost sharing scenario. These phenomena can be summarized as: $\phi_m^* = \phi_b^*$, $\xi_r^* = \xi_b^*$.

Second, in each model, the combined bilateral cost sharing effects are larger than those with only unilateral cost sharing, and the combined coordinated bilateral cost sharing effects are larger than that with uncoordinated bilateral cost sharing, that is, $\phi_m^* + \phi_b^* < \xi_r^* + \xi_b^*$, $\phi_b^* + \xi_b^* < \phi_c^* + \xi_c^*$.

Third, the cost sharing proportion provided by the manufacturer increases in the 90-day product life cycle, while the cost sharing proportion provided by the retailer decreases. The key reason is that, in the beginning of the product life cycle, the retailer needs to put more QR effort to ensure capturing high demand in the market while, when the product life cycle enters the later and mature sales periods with less demand in the market, the manufacturer has already gained distribution expertise and also has strong incentive to maintain a QR state by providing higher QR effort.

Finally, between the two bilateral cost sharing models (4 and 5), the coordinated cost sharing scenario promotes higher mutual cost sharing than that of the bilateral but not coordinated cost sharing scenario. Specifically, the cost sharing coefficient provided by retailer in Model 3 drops dramatically to a very low level in the final sales period ([81,90]) due to the lack of the supply chain coordination.

5.1.5. Developing theoretic themes

There are several theoretic themes that can be developed from the above numerical analysis:

Theme 1. The bilateral cost sharing contract coordination creates the best synergistic effect.

In contrast to other models, in Model 5, the product value is the highest, the manufacturer and retailer invest the highest QR effort, provide the highest cost sharing ratio, and the supply chain and its members achieve the highest profits.
From the perspective of total profit obtained over the 90-day product life cycle, the manufacturer's total profit is higher than the retailer's. At the same time, as the product lifecycle evolves, the manufacturer provides an increasing percentage of cost sharing and the retailer provides a decreasing percentage of cost sharing. This precisely illustrates the superiority of the bilateral cost sharing contract coordination mechanism. Under coordination, instead of only considering its own high profit, manufacturer provides solid help and dependence to retailer, creating a virtuous supply chain relationship. Both the supply chain and its members benefit from it.

These findings fully validates that the combination of bilateral cost sharing contract and coordination mechanism will promote the optimal QR construction of FFP supply chain.

Theme 2. QR effort investment follows the FFP value attenuation regularity.

In each sales stage, the product value, the QR effort invested by the manufacturer and the retailer, and the daily profit are lower than in all the previous stage. Also, they are lower in discount period in each sales stage than in the regular sales period. This is mainly due to the interaction between QR effort and FFP value. Manufacturer and retailer invest QR effort to reduce the loss of product value and compensate for the decline in profit, so the level of QR effort is related to the objective factor of the decline in product value over time. For manufacturer and retailer, it is worthwhile to invest high level of QR effort in products with high value, but it is undoubtedly wasteful for products with little value.

Theme 3. Cost sharing is better than without cost sharing, bilateral cost sharing is better than unilateral cost sharing.

In the comparison of all models, the QR efforts invested and profits achieved by manufacturer and retailer in the without cost sharing scenario are the lowest, so this paper considers without cost sharing scenario as the least efficient way.

Comparing the QR efforts, both manufacturer and retailer tend to invest lower levels of QR effort when they unilaterally share costs for another member, but invest higher levels of QR effort when the other member shares costs for itself. Considering the cost sharing coefficient, when manufacturer or retailer under unilaterally cost sharing scenario, it is willing to provide the same percentage of cost sharing as in the bilateral cost sharing scenario. In the bilateral form, both the manufacturer and the retailer participate in cost sharing, whereas in the unilateral form only one member provides cost sharing, so the combined cost sharing percentage in the bilateral form is higher than the unilateral cost sharing.

It is easy to find from the above phenomena that the implementation of cost sharing is beneficial, and the bilateral form is more advantageous than the unilateral one.

5.2. Sensitivity analysis

In the numerical analysis section, Model 5 is identified as the model with the best optimal outcomes. Thus, in this section, the sensitivity analysis of key parameters will focus on Model 5.

5.2.1. Parameters related to the product value decay differential equation

$m$ and $n$ are the coefficient of $E_M(t)$ and $E_R(t)$ in the product value decay differential equation that calculates the product value. The higher $m$ and $n$ are, the higher the product value is. Figure 7 presents the relationship between the profits and the changes of $m$ and $n$.

In Figure 7, when $m$ increases from 0 to 1 and $n$ remains unchanged, the profits of both the manufacturer and retailer will increase, and thus the supply chain total profit will also increase. When $m$ is lower than 0.8, the profit of the manufacturer is larger than that of the retailer but when $m$ is higher than 0.8, the situation will be reversed. This trend implies the contribution of increased manufacturing efficiency to the profit growth of both the FFP supply chain and its members. In addition, for the manufacturer, manufacturing efficiency need not be increased to an excessive degree; if manufacturing efficiency is too high, manufacturer’s profit growth will slow down.
Figure 7. Impact of $m$ or $n$ changes on total profits. (a) $m$ (baseline = 0.4) and (b) $n$ (baseline = 0.6).

Figure 8. Impact of $\theta$ changes on total profits.

Similarly, when $n$ increases from 0 to 1 and $m$ remains unchanged, the profits of both the manufacturer and retailer will increase, and thus the supply chain total profit will also increase. In addition, as the parameter $n$ increases, the manufacturer’s profit is always higher than the retailer’s. This finding suggests that both the FFP supply chain and its members benefit from the increasing marketing efficiency. In addition, although retailer’s performance is always lower than manufacturer’s, its growing rate is faster than manufacturer’s when marketing efficiency increases.

Comparing the impact on the profits from the changes of $m$ and $n$ in Figure 7, it shows the profit contribution of the manufacturer’s QR effort is greater than that of the retailer in the omnichannel supply chain. At the same time, both manufacturing efficiency and marketing efficiency improvements can significantly improve the profit growth rate of retailer. Finally, relatively speaking, manufacturing efficiency has a greater impact on total supply chain profit than marketing efficiency.

As seen in Figure 8, the higher $\theta$, the lower the profits of the supply chain and its members. This indicates a decrease in product value due to the presence of value decay rate, which ultimately leads to the decline in profits. Significantly, the profits decrease sharply at lower decay rate level, and decrease more smoothly when the decay rate gets higher. This phenomenon shows that the decay rate of new products is low at the beginning of the life cycle, and products with high value can bring high profits for manufacturer and retailer. When the decay rate is high, the low-value products are no longer easy to attract consumers, but the profit curve shows a
smooth decreasing trend because the investment to the product is also decreasing at this time, and the supply chain and its members can still profit from the sales process.

5.2.2. Parameters related to QR effort costs

\( k_m \) and \( k_r \) are the cost influence coefficients of the manufacturer’s and retailer’s QR efforts costs respectively. Figure 9 presents the impact of \( k_m \) and \( k_r \) changes on the total profits of the manufacturer, retailer and supply chain.

First, the profits of the supply chain and its members show a decreasing trend with the increase of both \( k_m \) and \( k_r \). The supply chain and its members achieve higher performance when \( k_m \) and \( k_r \) are at lower levels, it means that, the performances of manufacturer and retailer are more sensitive to QR cost; while when \( k_m \) and \( k_r \) are larger, the decreasing trend of the performance flattens out and it shows that the effect of QR cost on performance is no longer strong. Moreover, comparing the changes in \( k_m \) and \( k_r \) reveals that all the performance are higher in the case of changes in \( k_r \) than that in \( k_m \).

From the above phenomenon, it is easy to see that QR cost has a limited impact on performance. Only when the cost coefficient is small (the cost is low), so that the profits of the supply chain and its members are at a high level. And when the cost coefficient increases, although the QR cost rises, the benefits of QR construction make the profit decrease less. Also, it can be found from the figure that having more QR cost invested by the retailer is more beneficial for all parties because the retailer’s cost coefficient outperforms the manufacturer’s one for the supply chain and its members at any value taken.

5.2.3. Parameters related to retailer

\( \lambda \) is the ratio of the online channel sales to the omnichannel sales measured in percentage. As shown in Figure 10, as \( \lambda \) increases, the profit of the retailer decreases, thus leading to lower total supply chain profit. For retailer, the higher the proportion of online channel, the higher the cost of channel construction, and therefore the profit of retailer decreases. Since manufacturer does not need to build omnichannel system, manufacturer’s profit will not affected by the change of channel ratio. This finding suggests that a high percentage of online channel in the omnichannel is not always beneficial.

\( \rho \) is the discount rate at the discount sales period in the 90-day product life cycle. As it is shown in Figure 11, when \( \rho \) increases from the baseline 0.1, three total profits drop dramatically until it reaches 0.5 and level off afterwards at very low total profit levels. Since the FFP product value will decay along the timeline, it is better to sell as many as possible the product early in the fashion season to minimize the loss due to large discounts at the later stage. This finding provides a strong advocacy for utilizing the coordinated QR effort cost sharing model by the omnichannel to stimulate more demand of FFP in the early stage of the fashion season.
5.2.4. Parameters related to demand function

As seen in the Figure 12, the larger the $\alpha$ the greater the profits of the FFP supply chain and its members. In particular, while retailer’s profit is always lower than manufacturer’s, retailer’s profit growth rate is higher than manufacturer’s profit growth rate. This finding suggests that the profits of the FFP supply chain and its members are sensitive to the QR effort invested by the manufacturer. Specifically, a larger $\alpha$ implies that the manufacturer’s QR effort has a greater impact on demand, when the expansion of demand will lead to higher profits. It can be seen that manufacturer invest QR effort and consumers are more satisfied with the products and increase the purchase demand, which is beneficial to the profits of both manufacturer and retailer.

From Figure 13, it can be seen that the larger the $\beta$ the higher the profits of the supply chain and its members. Although the manufacturer’s profit is always higher than the retailer’s, the growth rate of the retailer’s profit is higher. This trend indicates that the profits of the supply chain and its members are sensitive to the QR effort invested by the retailer, as reflected in the expansion of demand as $\beta$ increases, which ultimately leads to higher profits. In a practical sense, the retailer invest QR effort to stimulate consumers to generate a higher purchasing desire, thereby increasing demand and achieving higher profits for the supply chain and its members.
In Figure 14, the larger the $\gamma$, the higher the profits of the manufacturer, retailer, and supply chain are, and the marginal growth rate of profits continue to rise. At the stage of $\gamma < 0.6$, the manufacturer’s profit is higher than the retailer’s, and when $\gamma > 0.6$, the retailer’s profit exceeds the manufacturer’s. This phenomenon reflects the fact that consumer preference has a significant contribution to profits. Especially, the strengthening of consumer preference degree is beneficial for retailer.

Figures 15 and 16 have similar trends, with more increasing values of $g$ and $h$ leading to higher profits for manufacturer, retailer, and the whole supply chain. Where, when $g$ and $h$ take values $< 5.5$, manufacturer’s profit is higher than retailer’s profit, while when $g$ and $h$ take values $> 5.5$, retailer’s profit exceeds manufacturer’s profit. Moreover, $g$ contributes more to all the profits than $h$. These characteristics can be summarized in the following findings. With good service provided by the offline channel, whether consumers only purchase in the offline channel or have the willingness to purchase in the online channel, there is a positive effect for the whole supply chain and its members to improve their performance. It is worth mentioning that the profit of retailer exceeds that of manufacturer only when offline channel customer retention or willingness to purchase online channel is at a high level. In addition, if offline stores offer service that result in consumers’ high willingness to...
purchase online, it is more beneficial for the manufacturer, the retailer, and the supply chain than if consumers are only retained in the offline channel.

From Figure 17, it is easy to find that $\eta$ has a negative effect on the profit of the supply chain and its members, and the larger the $\eta$ is, the lower the profits are. This trend indicates that profits decrease as the impact of FFP price on demand increases. However, at the same time, it can be observed that even if the impact of FFP price on demand reaches a high level, the decline in profits is very limited. This finding shows that, for consumers, the price of FFP is no longer a key factor in purchase decision. For the supply chain and its members, low pricing strategy is also no longer the main mean of attracting consumers.

5.2.5. Findings from the sensitivity analysis

(1) The parameters related to QR effort

The parameters related to QR effort include mainly the coefficients $m$ and $n$ of manufacturer’s and retailer’s QR effort on the FFP value, and the coefficients $\alpha$ and $\beta$ of manufacturer’s and retailer’s QR effort on demand. Each of these parameters can effectively amplify the role of QR efforts invested by manufacturer and retailer.
Firstly, from the sensitivity analysis of the parameters $m$ and $n$, it is clear that the improvement of both manufacturing efficiency and marketing efficiency contributes significantly to the profit growth of the supply chain and its members. For total supply chain profits, manufacturing efficiency has a greater impact on the supply chain than the same level of marketing efficiency. For manufacturer, the increase in manufacturing efficiency is not always beneficial, and being at too high a level will hinder profit growth. For retailer, although profit is always lower than that of manufacturer, high levels of manufacturing efficiency and marketing efficiency can lead to higher profit growth rate for retailer.

Similarly, sensitivity analysis of the parameters $\alpha$ and $\beta$ show that the higher the product satisfaction or the stronger the purchase desire, the greater profits of the supply chain and its members will expand. From the overall supply chain perspective, product satisfaction has a greater impact on total profit than the same level of purchase desire. From the manufacturer’s perspective, both higher product satisfaction and purchase desire lead to higher profit for the manufacturer than for the retailer. From the retailer’s perspective, high levels of product satisfaction and purchase desire can lead to rapid growth in retailer profit.
(2) The parameters related to FFP value and price

The parameters related to the FFP value mainly include $\theta$ and $\gamma$, and the parameter related to the FFP retail price is $\eta$.

The sensitivity analysis of $\theta$ conclude that profits decrease due to the presence of FFP value decay rate, and profits decrease smoothly at high degree of FFP value decline.

The sensitivity analysis of $\gamma$ outlines the positive effect of consumer preference on profits and that stronger consumer preference is more beneficial to retailer.

The sensitivity analysis of $\eta$ reflects the trend that profits are affected by retail price and decrease smoothly, and it is easy to find that consumer’s purchase decision is less influenced by price.

(3) The parameters related to the omnichannel

The main parameters that reflect the omnichannel characteristics are $\lambda$, $g$ and $h$.

First of all, the strong development of online channel is not always beneficial for retailer and supply chain.

In addition, the practice of enhancing customer retention through offline service and attracting traffic through online channels is conducive to expanding profit margins. If offline service can attract consumers to purchase online, it will be more beneficial than only attracting customers to spend offline. For retailer, the effect of service generation has to reach a very high level in order to obtain higher profit than the manufacturer.

6. Managerial insights and research extensions

Based on the numerical and sensitivity analyses of the previous section, this section will explore and derive the managerial insights and discuss the potential research extensions for this fast fashion and quick response study.

6.1. Managerial insights

6.1.1. Insights for the supply chain

(1) Improve QR efforts to delay FFP value decay

From the numerical analysis findings discussed in Section 5.1, the product value grows at the early stage to the highest value and then declines along the product life cycle which would then cause the decline of the manufacturer’s and retailer’s QR efforts and eventually leads to the reduction of both the manufacturer’s and retailer’s daily profits. Thus, to ensure a higher total profit for the supply chain members, the members should seek effective ways to reduce the product value decay, accelerate the sales of more products in the early stage of the product life cycle, or even shorten the product life cycle.

It is examined from the numerical analysis that increasing the QR effort to the optimal level is not only an important means to mitigate the value loss of the product, but also to create more demand and higher profits for the supply chain. An emerging “ultra-fast” fashion supply chain in the FFP industry [6] is actually in line with this insight. Ultra-fast fashion has a direct-to-consumer business model with a focus on producing clothes on an on-demand basis. It selects onshoring and/or nearshoring production with a strong connection with suppliers. No excess inventory or a minimum reasonable inventory is produced. Ultra-fast fashion may be called digitally native retailing. They are born online, with a focus on customer experience gained from a one-to-one relationship, and with a vertical integration strategy [49]. It is highly technology-focused, as it uses information technology assets and know-how to create business value. Integrated QR effort is one of the key know-hows.

It is also worth mentioning that it is very important to judge the timing of putting in QR effort. The purpose of QR effort contribution is to slow down the decay rate of product value, but the decline of product value is inevitable because of the existence of objective regularity. Therefore, it is suggested that supply chain members invest QR efforts at the right time in the product life cycle, increasing the invest level when the product value is high and conversely reducing the input when the product value is low.
(2) Promote the synergy of supply chain members

In five modeling scenarios, the model that uses bilateral cost sharing contract for coordination (Model 5) can generate the highest product value, QR effort, and demand over the product life cycle, resulting in the highest profit for the supply chain and its members. First, QR construction requires a huge investment that no member of the supply chain can complete alone, and the contractual coordination scenario can ignite the highest QR effort cost-sharing ratio between the manufacturer and the retailer. In other words, in this scenario, it is effective for manufacturer and retailer to collaborate and bear more of each other’s QR effort cost, both reducing cost and increasing profit. At the same time, because of the high cost of establishing QR, under the situation that achieved optimal QR effort, it is suggested that supply chain members should try to control cost.

Moreover, QR investment in individual segments is lacking meaningfulness and requires active participation of members in each segment to form a quick response supply chain. With this contractual coordination, the manufacturer and retailer are on an equal footing and jointly invest the optimal level of QR effort to extend the overall benefits of the supply chain, achieving a win-win situation rather than considering only their own self-interest.

In addition, this scenario only considers the case where all supply chain members comply with the contract and are consciously bound, and it is recommended to consider adding a penalty mechanism for breach of contract in practical operation.

(3) Increase the manufacturer’s cost sharing coefficient and decrease the retailer’s cost sharing coefficient over the product life cycle

From the perspective of overall supply chain benefits, increasing the manufacturer’s cost sharing coefficient and reducing the retailer’s cost sharing coefficient as the product lifecycle progresses is a very essential measure. In addition to bearing the cost of QR efforts, it costs retailer a significant amount of channel cost to construct omnichannel, so manufacturer is often more profitable than retailer. However, retailer creates higher demand by building omnichannel, and manufacturer also can benefit from retailer’s omnichannel construction. With retailer bearing high channel cost, it is even more important for manufacturer to bear some QR effort cost for retailer to encourage retailer to invest in QR effort. The manufacturer’s QR effort is mainly devoted to the manufacturing and shipping process in the early stage of the product, while the retailer’s QR effort plays an important role mainly in the sales process in the later stage. Thus, as the product lifecycle evolves, the manufacturer bears decreasing cost and has the ability to increase its cost sharing ratio. Retailer, with the help of the manufacturer and no worries, can reduce their cost sharing ratio accordingly and invest in QR with greater confidence.

6.2. Insights for manufacturer

(1) Improve proper manufacturing efficiency

From the results of the sensitivity analysis, it can be concluded that the manufacturer is recommended to increase the manufacturing efficiency and this move can increase the profits of the manufacturer, the retailer and the whole supply chain (Sect. 5.2.1). This also represents that manufacturer must pay more attention in manufacturing process. Even though the modern external environment and operation method has been altering, good and fast manufacturing efficiency is still very important for manufacturer and the other supply chain members.

However, when the manufacturing efficiency is very high, the retailer’s profit is higher than the manufacturer’s profit. It can be seen that when the manufacturing efficiency is too high, the growth rate of manufacturer’s profit decreases and is completely beneficial to the retailer. Therefore, from manufacturer’s aspect, manufacturer should provide a proper level of manufacturing efficiency.

(2) Improve product satisfaction

Improving product satisfaction can effectively contribute to the performance of manufacturer, retailer and the supply chain (Sect. 5.2.4). For consumers, satisfaction with the product itself is an important influence on their
purchase decisions. High-quality products themselves are excellent salesmen, and create value for customers, quality directly affects customer satisfaction with the product.

Compared with traditional brands, fast fashion has the ability to keep up with the fashion trends in design and update frequently, and respond quickly to the consumer psychology of young people in pursuit of fashion. The concept of fast fashion has changed the original consumption and lifestyle of customers, and clothing or other products have been transformed from durable consumer goods to fast consumer goods. The style design is getting more and more attention. Therefore, it is recommended that manufacturer should pay attention to the role of the product itself and strengthen the quality of the product, while capturing fashion information and consumer psychology in time to improve consumer satisfaction with the product.

6.3. Insights for retailer

(1) Improve marketing efficiency

It is easy to see that improved marketing efficiency by retailer can lead to significant improvements in the performance of the supply chain and its members (Sect. 5.2.1). Consumers connect with products through offline stores or online channels, and it is important for retailer to focus on the efficiency of the environment and interaction in this process.

Firstly, store location is very important. Brands of high-frequency consumption products like FFP generally tend to open offline stores in core shopping areas and create a unique environment to get enough crowd flow. They also sell their products on large online platforms or build their own online channels to attract more demand. Moreover, for consumers, the process of consumption is also the process of interaction with the brand and sales staff, in which people play an important role that should not be ignored. Many fast fashion brands adopt membership system, so that consumers gradually embark spontaneous purchase desire and brand dependence. By becoming a member, the consumers establish a sustainable relationship with the brand beyond the transaction. Compared to ordinary users, members are more valuable, both in terms of revenue contribution, cost control, and brand recognition and word-of-mouth communication.

(2) Integrate the advantages of online and offline channels

From the sensitivity analysis (Sect. 5.2.4), it can be found that the offline stores provide quality service not only can expand the demand through the improvement of customer retention, but also have an attractive effect on the online channel.

The Internet provides information, compared with offline channel, is fast, complete, and convenient to make price comparison, so in recent years the online channel has gradually become the largest “department store”. This is the advantage of the online channel, but the information advantage provided by the online channel cannot instead of experiencing. Take buying clothes as an example, consumers who buy clothes from online channels can only make purchase decisions based on their feelings because they cannot try them on, leading to an increase in dissatisfaction and return rates. It can be seen that, online channel is not always advantageous.

The best way is to integrate the information advantage of online channel and the experience advantage of offline channel to create “experience stores”. Encourage consumers to experience the real products in offline stores, fully adequate the relevant information online, and then choose either channel to make a purchase based on their own product preference. This initiative allows both online and offline channels to leverage their strengths and complete transactions with an integrated omnichannel system. For retailer who constructs the omnichannel, the measure expands demand and boosts profits, whether consumers purchase from online or offline channels. At the same time, retailer should consider the cost of channel construction and try to attract customers in lower cost channel.

(3) Use less pricing strategy

From the above analyses, it is easy to find that the factors influencing consumers’ choice of products are diversified due to the construction of QR and related capabilities. However, consumers are less sensitive to FFP
price, and the pricing strategy is not so effective anymore. It is no longer a good idea for FFP brands to focus on low price sales; instead, they should consider the purchase decision from the consumer’s perspective and adopt a more humane and approachable approach to close the distance with consumers.

6.4. Discussion

ZARA has developed a unique supply chain structure that possesses the omnichannel characteristics of Model 5 in this study. ZARA produces the core fashion products by himself and distribute to his outsourced local logistics firms and deliver to his worldwide stores or e-commerce customers for sales. In this highly choreographed supply chain, the QR efforts are well planned and highly integrated from the manufacturing operations to the store and e-commerce platform sales. About 20% of Zara’s total production is pre-made, while 80% is produced according to the market response [25]. In contrast, H&M, a major competitor of ZARA, has designed a less choreographed supply chain with more than 700 independent suppliers instead of owning its own factories. This supply chain structure is similar to Model 4 of this study. However, due to the complexity of its supply base and lower price goal, 80% of clothes must be produced in advance and only 20% are made based on the most current market trend [24].

In a FFP omnichannel, many marketing decisions have to be made dynamically with respect to the market and supply chain situations. It is important to design a sense-and-respond supply chain similar to ZARA in which the retailer should develop the information system to “sense” the market and supply chain changes while the manufacturers and suppliers can “respond” quickly to these changes. The fast fashion retailer must establish good relationship with its vertical business partners, particularly textile suppliers and garment manufacturers, in the fast fashion omnichannel to create short lead times. Sophisticated logistic technologies that support the quick response best practices such as collaborative planning forecasting and replenishment (CPFR) [45] and vendor-managed inventory (VMI) [57] should be deployed jointly by the omnichannel members to distribute the fast fashion product without delays.

6.5. Research extensions

Due to the limit of time and space, this study only selects few key parameters to conduct sensitivity analysis. Future research can expand by selecting other parameters that may bring out good managerial insights. For example, since the fast fashion industry are seen with a trend of shorter product life cycle, a good extension of future research would be to conduct a sensitivity analysis on a time range shorter than 90 days used for this study.

Regarding the wholesale price, \( w \), set by the manufacturer, the existence of a zero-sum game nature between the manufacturer and retailer is found when \( w \) changes. Since the revenue sharing scheme in the supply chain can shift the zero-sum game to a cooperative game, this issue can be investigated in the future research.

Since advertisement such as the large brand logo on the exterior wall of the shopping malls, the spokesperson posters on the stores and the online advertisements may create more sales requiring fast response, how advertising affects QR effort would be a good extension to the further research.

7. Conclusion

The key theoretical contribution of this study is to explore quantitatively how QR effort affect a FFP omnichannel supply chain with a non-immediate attenuation nature that is still absent in the literature. Five differential game models are developed to study the QR effort’s impact on the performance of a two-stage FFP omnichannel with a manufacturer and a retailer. The numerical and sensitivity analyses have found that, in order to achieve higher profits, cost sharing is better than without cost sharing; bilateral mechanism is better than a unilateral mechanism; and contract coordination mechanism is better than non-contract coordination mechanism.

Three theoretical modeling themes are developed from this study. First, a higher level of QR efforts will lead to a higher product value and a higher product value can create a higher demand. Second, the level of QR efforts
involved by the manufacturer and retailer is the highest under the coordinated cost sharing contract mode and creates the best synergistic sales effect for the FFP omnichannel members. Third, the bilateral coordinated cost sharing scheme can ignite the highest QR efforts cost sharing proportions from both the manufacturer and retailer and generate the highest total accumulated profits in the FFP product life cycle.

The theoretical themes imply that the FFP omnichannel practitioners should put more resources and energies in coordinating their QR efforts in the supply chain. Importantly, they should collaborate closely to confine the costs of QR effort investment through a smart selection of the right QR technologies and a better utilization of these technologies to develop and support a highly sense-and-respond supply chain operations model. Furthermore, other than the QR effort cost sharing coordination, a revenue sharing mechanism should be incorporated into the supply chain contract so that the business goals of the manufacturer and retailer can be aligned to cultivate a win–win culture.

As an initial attempt to explore the financial performance of a FFP omnichannel with a non-instantaneous attenuation characteristic, authors hope that the findings and results of this study lay down a solid foundation for the future extension of this research.

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