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Quick response and supply chain structure with strategic consumers

Daojian Yang*, Ershi Qi, Yajiao Li

College of Management and Economics, Tianjin University, Tianjin 300072, China

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ABSTRACT

This work explores the impact of quick response on supply chain performance for various supply chain structures with strategic customer behavior. By investigating pricing and inventory decisions in decentralized supply chains under revenue-sharing contracts and in centralized supply chains, we study the performance of four various systems and compare the value of quick response in different supply chain structures. The results show that if the extra cost of quick response is relatively low, the value of quick response would be greater in centralized systems than in decentralized systems. On the other hand, if the extra cost is high, decentralized supply chains reap more incremental profits from adopting quick response. We also find that revenue-sharing contracts enable a decentralized supply chain to outperform a centralized supply chain, but only allow limited flexibility of allocating total profits between a manufacturer and a retailer.

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1. Introduction

As firms in the apparel industry and beyond pay increasing attention to quick response [1], they face essential decisions on the structures of their supply chains: *centralized supply chain or decentralized supply chain*? Different companies may choose different structures. For example, Zara is quite famous for constructing a highly integrated supply chain [2,3]. It makes much effort to shorten the supply chain, including striving to own and manage all the stores [4]. H&M, by contrast, keeps a long supply chain. Its products are totally manufactured by independent suppliers [5]. It sources a lot from distant areas like Asia, where the production cost is low [6]. Mango, an international fast fashion company having presence in more than 100 countries [7], also operates a decentralized supply chain. The majority of its shops are franchise outlets [8]. A natural question to ask is: which system is likely to reap more *incremental benefits* from adopting quick response? It is for sure that a well devised supply chain system would help to exploit quick response capabilities.

Quick response is an operational strategy designed to reduce lead times and improve supply flexibility [1,9]. It utilizes a range of technologies (such as enhanced information systems, and expedited logistics operations) to achieve its goal. In the middle 1980s, the first adoption of quick response took place in the apparel industry in the United States. Now quick response is successfully implemented in various industries. Zara, H&M, and Adidas are among the companies that invest in building quick response capabilities [10]. The benefits of quick response are well acknowledged [1,11,12]. Retailers in supply chains with quick response are able to adjust their ordering quantity rapidly, according to the market demand information gathered. Quick response enables firms to avoid overproduction, ensure low inventory levels, and counteract strategic customer behavior [13]. Furthermore, it is known that the value of quick response for a retailer, which is measured in terms of profit increment, is greater with strategic consumers than without [9]. Nevertheless, there is little research investigating the impact of quick response on the performance of decentralized supply chains with strategic consumers. So we aim to bridge this gap in the literature and answer the question we raise above.

In this paper, we analyze the decisions made by different members in various supply chain structures, and then compare the value of quick response in centralized systems with that in decentralized systems. Building upon the newsvendor model with strategic customers proposed in [14], our model considers four types of supply chains, namely: (1) decentralized supply chain without quick response, (2) decentralized supply chain with quick response, (3) centralized supply chain, and (4) centralized supply chain with quick response. In the absence of quick response, Su and Zhang [14] study the performance of supply chains taking into account strategic customers. They find that a decentralized supply chain could outperform a centralized supply chain under an appropriate wholesale price contract. The decentralized systems in this paper are governed by revenue-sharing contracts instead of wholesale price contracts. Revenue-sharing contracts have been extensively studied and could be viewed as generalized versions of

* Corresponding author. Tel.: +86 13821138396.
E-mail address: yangdaojian@tju.edu.cn (D. Yang).

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wholesale price contracts [15]. We would like to examine whether revenue-sharing contracts could help to achieve optimal supply chain performance. Our model begins with a decentralized supply chain, in which we analyze the retailer's decisions and the parameters in revenue-sharing contracts. Next we extend the model to incorporate quick response. To compare the value of quick response in alternative supply chain structures, we then introduce centralized systems, both with and without quick response. Further, we study the inventory decisions and the performance of the four supply chains, and then investigate the value of quick response both in centralized systems and in decentralized systems, analytically and numerically.

We now provide the main findings. First, we show that with strategic consumers, the value of quick response is higher in centralized supply chains than in decentralized supply chains, if the unit cost of products with quick response is close to the unit cost of ordinary products. This is a counterintuitive finding, because according to [9,14], one would expect that quick response would generate more value for decentralized systems. Thus, if a firm could vertically integrate its supply chain and make the best of quick response, thereby effectively reducing the additional cost of quick response, it would make more profits from implementing quick response, compared to a decentralized system. For instance, Zara is reported to have an extraordinary fast supply chain [2,3]. Chances are it does so well in quick response that its cost of an additional product after observing accurate demand would not be much higher than the unit cost of the initial inventory. However, if the extra cost of quick response is great, decentralized systems would reap more incremental profits.

Second, we find that revenue-sharing contracts are preferred over wholesale price contracts in decentralized supply chains with strategic customer behavior. This is because the revenue-sharing contract not only enables a decentralized system to outperform a centralized system, but also allows alternative allocations of profits between a manufacturer and a retailer. The wholesale price contract, by contrast, is known to only permit a particular division of the profits. Yet, the revenue-sharing contract imposes an upper bound on the retailer's share of the overall profits generated by the supply chain. In consequence, it fails to allow full flexibility of dividing profits. This is in contrast to the prevailing view that revenue-sharing contracts support arbitrary split of total profits between members within the supply chain. As the retailer's bargaining power grows, it may accept neither revenue-sharing contracts nor wholesale price contracts.

Third, limiting initial inventory often works well for discouraging strategic customer behavior, provided that the supply chain could convince consumers of its credibility. Quick response, as well as decentralization, would just serve as a means to persuade strategic customers that the supply chain would stick to its decision of low stocking level. We show that the equilibrium inventory is lower in a decentralized supply chain with quick response, compared to in a centralized supply chain with or without quick response. Low inventory levels reduce the possibility for the supply chain to salvage excess products, which increases strategic consumers' willingness to buy early. The supply chain could thus charge a higher retail price, contributing to the increment of profits.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 introduces the model of a decentralized supply chain. Section 4 extends the model by studying a decentralized supply chain with quick response. Section 5 addresses the model of centralized supply chains. Section 6 compares the performance of various supply chains and investigates the value of quick response. Section 7 presents a numerical study. Section 8 provides discussion, extension and managerial implications. Section 9 offers concluding remarks.

2. Literature review

Our work is related to three streams of research: the literature on consumer behavior in operations management, the literature on quick response, and the literature on supply chain contracting.

Researchers have recognized the importance of investigating consumer behavior in operations management and built a variety of models [13,16]. Strategic customer behavior, well studied in economics [17] and marketing [18–20], is introduced into a supply chain setting by Su and Zhang [14], where the impacts of strategic customer behavior on system performance under various contracts are analyzed. Khouja, Park, and Zhou [21] consider a newsvendor problem, in which patient consumers could get free gift cards offered by retailers at the end of the season if the consumers choose to delay their purchase. Dasu and Tong [22] conclude that neither a posted pricing scheme nor a contingent pricing scheme is dominant when a monopolist sells short life cycle products over a finite time horizon to strategic consumers. Anily and Hassin [23] study a deterministic problem of pricing and replenishment, where strategic consumers take into account holding or shortage cost. Other examples include strategic customers anticipating future prices of products [24], determining which product variant to buy [25], making decisions concerning group buying [26], and considering search costs [27]. Besides strategic customer behavior, researchers also explore consumer learning behavior [28,29], consumer inertia behavior [30,31], bounded rationality [32], customer disappointment aversion [33], and hyperbolic discounting [34] in operations management.

Our model in this paper builds on the newsvendor model with strategic customer behavior developed by Su and Zhang [14], but our analysis is distinct in that we consider the order adjustment problem of quick response strategy in a supply chain setting with strategic customers. To the best of our knowledge, the influence of strategic consumer behavior on the value of quick response in a decentralized system has not been addressed. Additionally, we obtain an unexpected finding that the value of quick response could be greater in centralized supply chains than in decentralized supply chains when the additional cost of quick response is low. Our work employs the revenue-sharing contract which is not studied in [14], and derives an interesting result: in the presence of strategic consumers, revenue-sharing contracts only allow limited flexibility of dividing overall profits, though they are favored over wholesale price contracts.

There exists an extensive literature exploring quick response in operations management [1,11,12,35]. These papers usually treat quick response as a vehicle to reduce lead times and mitigate demand uncertainty. Among them, a few recent studies [9,36,37] are most relevant to our work. They address the impact of strategic customer behavior on the value of quick response. Cachon and Swinney [9] find that quick response capability provides far more value to the retailer if strategic consumers are present than if all consumers are myopic. Our paper differs from the above works [9,36,37] in that (1) this paper considers not only the centralized supply chain with strategic consumers but also the decentralized supply chain composed of more than one firm, whereas they [9,36,37] investigate only the interaction between strategic customers and a single seller, (2) our work compares the performance of centralized supply chains with that of decentralized supply chains, and studies the value of quick response in various systems with strategic consumers, (3) this paper shows that the centralized system could harvest more incremental profits from implementing quick response, relative to the decentralized system, if the extra cost of quick response is relatively low, (4) our study suggests that firms may employ decentralized structure for their supply chains if they are unable to effectively reduce the additional cost of quick response, (5) we recommend that decentralized supply chains under wholesale price contracts may replace their contracts with revenue-sharing contracts, which are observed in franchise agreements employed in the apparel industry, and (6) we suggest that companies, especially the ones in decentralized systems, should reduce the initial inventory accordingly when implementing quick response, so as to better discourage strategic customer behavior.

Another three works that explore decentralized supply chains with quick response are also quite relevant to our paper [38–40]. Iyer and Bergen [39] study the impact of adopting quick response on each of the two members within a two-echelon supply chain. Chow, Choi, and Cheng [38] consider a quick response supply chain with Minimum Order Quantity (MOQ) requirement and put forward a dynamic MOQ policy to coordinate the system. Zhang, Gou, Zhang, and Liang [40] demonstrate the advantages of quick response in a supply chain while studying the influence of reference price effects on pricing. The important distinction of our work is that it analyzes the value of quick response with strategic consumers and obtains different insights.

Supply chain contracting has drawn lots of attention from researchers [15,41,42]. Different entities in decentralized systems usually have different incentives [43,44]. To coordinate supply chains, various forms of contracts (such as wholesale price contracts, quantity-discount contracts, buyback contracts, and revenue-sharing contracts) are designed and used. Our work is closely related to the works on revenue-sharing contracts, as the supply chains in this paper are governed by revenue-sharing contracts. Cachon [15] surveys various contracts leading to supply chain coordination, among which revenue-sharing contracts arbitrarily allocate overall profits of a supply chain. More recent studies that are relevant to our paper include [45–47]. Kong, Rajagopalan, and Zhang [45] find that revenue-sharing contracts in a supply chain promote information sharing, as well as preventing information leakage. Palsule-Desai [46] builds a model under a revenue-dependent revenue-sharing contract and shows that both the revenue-independent revenue-sharing contract and the revenue-dependent contract can coordinate supply chains, but sometimes the latter performs better than the former. Wang, Lau, and Hua [47] put forward modified revenue-sharing contracts that outperform classic revenue-sharing contracts, when the manufacturer is uncertain about the system parameters. Consumers in these works addressing revenue-sharing contracts are assumed to be myopic, whereas customers in this paper behave strategically.

3. The model

Our model follows [14,36]. We assume that a single manufacturer sells products through a retailer to consumers over two periods: “full price period” and “salvage price period”. The retailer here is similar to the seller in the newsvendor problem [48] that takes into account strategic customer behavior.

The selling season begins in the full price period, in which the product is sold for a full price p. If there is inventory remaining at the end of the full price period, the retailer sells the product at a salvage price s in the salvage price period. Suppose that s is exogenously given and the demand of the exogenous salvage market for the product is infinite. In the salvage market, strategic consumers have the priority to receive the product.[1] On the other hand, if products are sold out in the full price period, there will be no salvage price period. Customers have constant valuation v for each unit. Strategic consumers make intertemporal decisions to maximize their surplus. Their reservation price for the product is r, which is the highest price they are willing to pay for the product in the first period. All strategic customers are homogeneous. $A \geq 0$ denotes the random aggregate demand of strategic customers. $G(a)$ denotes the distribution function of demand A. We use an upper bar for complement function where relevant, e.g., $\overline{G} = 1 - G$. The density function of demand A is denoted by $g(a)$. Assume $g(a)$ is continuous and $g(a) > 0$ for tractability. The demand distribution is assumed to have an increasing failure rate.

3.1. Revenue-sharing contract

As for the transactions between the manufacturer and the retailer, they are governed by a revenue-sharing contract rather than a wholesale price contract.[2] There are two parameters in the revenue-sharing contract, denoted by (w, ϕ), where $0 < \phi \leq 1$ and $w \geq 0$. One is the wholesale price w; the other is ϕ, the retailer's share of revenue gained from selling products. Hence, the share for the manufacturer is $(1-\phi)$. For each unit procured from the manufacturer, the retailer pays the wholesale price w plus the share $(1-\phi)$ of the revenue.

3.2. Timeline of events

Here we present the timeline of events in our model. First of all, the manufacturer and the retailer agree on terms of a revenue-sharing contract (w, ϕ). Next, the retailer determines two variables to maximize its expected profit: one is p; the other is q, the order quantity to the manufacturer. Then, the selling season starts and consumers arrive. Products are sold at p in the full price period and consumers make choices between buying now or waiting. If there are leftover units at the end of the full price period, the retailer clears inventory at price s in the salvage price period. The timeline of events is shown in Fig. 1. We use backward induction to solve the game described above.

3.3. The retailer's pricing and ordering decisions

In this subsection, we study the retailer's pricing and ordering decisions by analyzing a game between the retailer and strategic consumers. Rational Expectations Hypothesis (REH) is used throughout the analysis to derive an equilibrium outcome. As the selling season starts, strategic customers time their purchase to maximize expected surplus. They form beliefs over the probability of obtaining a product in the salvage period and these beliefs must concur with outcomes according to REH. Hence, their expectations of the probability are $G(q)$, which is the actual probability. If a strategic consumer waits for sale, the surplus is therefore $(v-s)G(q)$. On the other hand, if the consumer buys immediately, the surplus is $v-p$. Accordingly, an individual strategic customer's maximum expected surplus is $\max(v-p, (v-s)G(q))$. This customer chooses to buy at the full price if and only if $v-p \geq (v-s)G(q)$, so $r = v-(v-s)G(q)$. On the basis of its anticipation of strategic customers' reservation price r, the retailer selects p to optimize its

[1] Strategic consumers are forward-looking and are keen to get the best deals. When a strategic customer decides to delay the purchase, the customer would actively gather information of the salvage period. Therefore, the strategic consumer is more likely to receive a product on sale than a normal bargain hunter, once the retailer marks down the price. For tractability, we assume that strategic consumers have the priority over bargain hunters to get the product in the second period (Su and Zhang [14], and Cachon and Swinney [36] make similar assumptions in their works). Section 8.2 provides an extension to the basic model with more general allocation rule.

[2] The wholesale price contract is investigated by Su and Zhang [14]. They find that a wholesale price contract could help a decentralized supply chain outperform a centralized one because of strategic customer behavior, but it fails to arbitrarily allocate profits between the two members within a supply chain. By contrast, it has been widely documented in operations literature that revenue-sharing contracts coordinate supply chains, as well as arbitrarily dividing total profits. Here, we aim to study advantages and disadvantages of revenue-sharing contracts with strategic consumer behavior. See Section 8.1 for more discussion on why we adopt revenue-sharing contracts in our study.

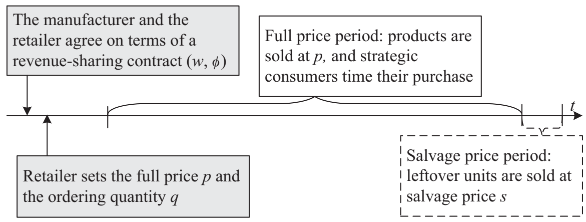

Fig. 1. Timeline of events.

profits. In the light of REH, the retailer correctly anticipates r, so it sets $p=r$, which leads to

$$p=v-(v-s)G(q). \tag{1}$$

As a result, all strategic consumers decide to purchase immediately in equilibrium.

Next, we calculate the retailer's profits under revenue-sharing contracts. In what follows, we use "$\wedge$" to denote minimum operation and "E" to denote the expectation operation. We also use the superscript j and the subscript s to denote "retailer" and "revenue-sharing", respectively. Under a revenue-sharing contract $(w,\ \phi)$, the retailer's profits are

$$\Pi_s^j(p,\ q)=\phi[(p-s)E(a\wedge q)+sq]-wq. \tag{2}$$

Here we suppose that the retailer shares all the realized revenue (including salvage revenue) with the manufacturer [15]. We assume that $w<\phi p$, since otherwise the stocking level q would be zero.

We are now prepared to derive p and q in equilibrium. Since the retailer determines these two variables to maximize $\Pi_s^j(p,\ q)$, we have the following proposition.

Proposition 1. Under a revenue-sharing contract $(w,\ \phi)$, the equilibrium price p_s and the equilibrium ordering quantity q_s of the retailer are given by

$$\begin{cases} p_s=s+\sqrt{\frac{(w-\phi s)(v-s)}{\phi}}, \\ \overline{G}(q_s)=\sqrt{\frac{w-\phi s}{\phi(v-s)}}. \end{cases} \tag{3}$$

Proof. All proofs are in the Appendix.

It is shown in Proposition 1 that as the revenue-sharing parameter ϕ decreases from 1, the equilibrium price p_s climbs, holding all else constant (i.e., w). Hence, the smaller the retailer's proportion of its realized revenue, the higher the retailer sets the full price p_s. Consequently, if the manufacturer would like to maintain a constant p_s while lowering the retailer's share ϕ, it should reduce the wholesale price w in the revenue-sharing contract simultaneously. Additionally, $\overline{G}(q_s)$ rises as ϕ falls, all else being equal. Therefore, as ϕ declines, so does the equilibrium stocking quantity q_s. In other words, when the retailer's proportion of its realized revenue decreases, the retailer will restrict its stocking quantity of the products.

3.4. Wholesale price and revenue sharing

Here we analyze revenue-sharing contracts, taking into account the retailer's pricing and ordering decisions specified in the above subsection. In a closely related study, Su and Zhang [14] investigate a wholesale price contract rather than a revenue-sharing contract. They demonstrate that: (1) there exists a wholesale price contract $w=w^*$ which leads to Π_q^*, the optimal profit under quantity commitment; (2) the retailer gets a fixed profit share (we denote this share by ϕ^* in this paper, so the manufacturer obtains a fixed share of $1-\phi^*$); (3) the retailer's optimal stocking quantity Q_q^* is induced by w^* in equilibrium and $\overline{G}\left(Q_q^*\right)=\sqrt{(w^*-s)/(v-s)}$. Now, we borrow w^*, ϕ^*, Q_q^*, and Π_q^* from their work to study the revenue-sharing contracts in this paper.

Suppose that each product costs the manufacturer c, and $s<c<p\le v$. Under a revenue-sharing contract $(w,\ \phi)$, the manufacturer's profits are

$$\Pi_s^m=(w-c)q+(1-\phi)[(p-s)E(a\wedge q)+sq]. \tag{4}$$

The superscripts m and sc stand for "manufacturer" and "supply chain", respectively. Thus the overall profits of the supply chain are

$$\Pi_s^{sc}=\Pi_s^j+\Pi_s^m=(p-s)E(a\wedge q)-(c-s)q. \tag{5}$$

According to the findings in [14], it should be clear that the optimal stocking quantity q_s^* must equal Q_q^*. This leads to the following result.

Proposition 2. Under the revenue-sharing contract $(w_s^*,\ \phi)$ in which $w_s^*=\phi w^*$, the supply chain as a whole attains the optimal profit Π_q^*. In addition, the retailer's profit share is $\phi\phi^*$, while the manufacturer's share is $1-\phi\phi^*$.

Revenue-sharing contracts could facilitate supply chain coordination here. As long as the manufacturer and the retailer agree to choose ϕw^* as the wholesale price in the contract, the supply chain system would achieve the optimal profits Π_q^*. Wholesale price ϕw^* in the revenue-sharing contract induces the retailer to choose the same stocking level as that under the wholesale price contract. As $0<\phi\le 1$, the wholesale price would be generally lower in the revenue-sharing contract than in the wholesale price contract. Observe that the wholesale price may even be lower than c when ϕ is sufficiently small, i.e., $\phi<c/w^*$.

Furthermore, the above revenue-sharing contract permits alternative profit divisions rather than one particular split of overall supply chain profit. Clearly, the manufacturer's profits fall and the retailer's profits rise as ϕ increases. Revenue-sharing contracts work well in a supply chain where there is a more powerful manufacturer, since it could capture most of the overall profits by reducing ϕ. In addition, the manufacturer has to lower the wholesale price to enlarge its profit share.

Nevertheless, the retailer has no chance of getting more than the share ϕ^* of realized profits. As the range of ϕ is $(0,1]$, the retailer usually gains lower profits under the revenue-sharing contract, as opposed to under the wholesale price contract above. In consequence, when the retailer dominates the supply chain, it may not favor revenue-sharing contracts. What we find here is different from the results in Ref. [15]. A revenue-sharing contract is often associated with full flexibility of allocating a supply chain's profit between its members. The reason why the contract here only has limited flexibility is that to achieve the optimal profits of the decentralized system, the system sets $w_s^*=\phi w^*$ rather than sets $w_s^*=\phi c$. Notice that $w^*>c$.

4. Quick response in the supply chain

Here we consider the adoption of quick response in the supply chain, in which the manufacturer and the retailer agree to a revenue-sharing contract $(w_1,\ w_2,\ \phi)$. Now, the retailer with quick response capability has two opportunities to submit the product order. Before the start of the selling season, the retailer has to determine q to place an initial order and the wholesale price for each product is w_1 at this time. As the selling season approaches, more demand information is gathered. At the beginning of the selling season, the retailer with quick response capability observes the accurate demand and has the option to submit a second order. The wholesale price is w_2 in the second procurement and $w_1<w_2$.

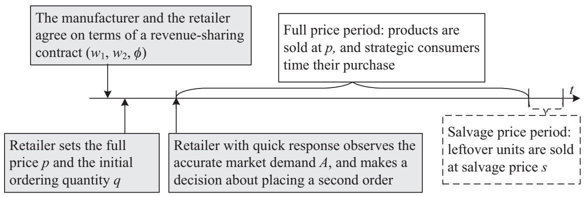

Fig. 2. Timeline of events in the presence of quick response.

We also use ϕ in the contract to denote the retailer's share of the realized revenue. When $\phi = 1$, the revenue-sharing contract is simplified to a two-stage wholesale price contract (w_1, w_2). c_1 is defined to be the ordinary production cost of the manufacturer for a unit product, and c_2 is defined to be the quick response production cost per unit. We assume $s < c_1 < c_2 < p$. Here, the timeline of events is depicted in Fig. 2.

4.1. The retailer's decisions with quick response

We proceed by looking at the retailer's inventory decision. The retailer maximizes its profit by setting the full price p and the initial stocking quantity q. As $c_2 < p$, the retailer will order adequate products in the second order, once it finds out that the actual demand of strategic consumers exceeds the quantity of the initial order. Therefore, when the retailer has the option of the second procurement, its inventory can always meet the aggregate demand of strategic customers.

In equilibrium, all strategic customers choose to purchase in the first period. One might argue that strategic customers may delay their purchase, as there is sufficient inventory for all strategic consumers. But here we assume that all strategic consumers purchase immediately because of the following reasons: (1) When the retailer observes that the demand exceeds q and then places a second order, the total quantity of the two orders equals the actual demand; in this case, the retailer would never mark down the price because it knows that all strategic consumers would buy at the full price eventually. (2) In order to persuade all strategic customers to buy immediately, the retailer could decrease the quantity of the second order by an infinitesimal amount; the required decrease is so small that we neglect it in the analysis.[3] As a result, the retailer marks down the price in the second period only if the initial stocking quantity q is larger than the realized demand.

In what follows, we use the subscript qr to denote "quick response". The profit of the retailer with quick response can therefore be expressed as follows:

$$\Pi^j_{qr}(q,p) = \phi[(p-s)E(a \wedge q) + sq] - w_1 q + (\phi p - w_2)\int_q^{+\infty}(a-q)g(a)da. \quad (6)$$

Suppose $\phi s < w_2 \le \phi p$. We use q_{qr} to denote the optimal initial stocking quantity resulting in the retailer's maximum profits. q_{qr} is thus characterized by

$$q_{qr} = \text{argmax}_q \Pi^j_{qr}(q,p). \quad (7)$$

So we have the following proposition concerning q_{qr}.

[3] Cachon and Swinney [36] also assume that all strategic consumers would purchase at the full price, when the retailer with quick response capability orders sufficient inventory to satisfy the total demand of all strategic consumers.

Proposition 3. The optimal initial stocking quantity of the retailer with quick response is given by

$$\overline{G}\left(q_{qr}\right) = \frac{w_1 - \phi s}{w_2 - \phi s}. \quad (8)$$

Proposition 3 demonstrates that for the retailer with quick response capability, the initial stocking level is related to the product cost within the initial order w_1, the product cost within the second procurement w_2, and the retailer's share ϕ. The stocking quantity q_{qr} decreases in w_1; thus the higher the cost of the product within the initial order, the lower the retailer sets its initial stocking level. In contrast, the stocking quantity q_{qr} increases in w_2; in other words, the retailer would increase the quantity of the initial order if the unit cost within the second order rises. In this way, the retailer would be able to reduce its total cost of the required products to entirely meet the volatile market demand.

4.2. Revenue-sharing contracts with quick response

Here we analyze revenue-sharing contracts in decentralized systems with quick response. From (6), we get the manufacturer's profit Π^m_{qr} as below.

$$\Pi^m_{qr} = (w_1 - c_1)q + (w_2 - c_2)\int_q^{+\infty}(a-q)g(a)da + (1-\phi)[(p-s)E(a \wedge q) + sq] + (1-\phi)p\int_q^{+\infty}(a-q)g(a)da. \quad (9)$$

Because $\overline{G}\left(q_{qr}\right) = (w_1 - \phi s)/(w_2 - \phi s)$, it follows from (1) that the full price p is now $p = s + (v-s)(w_1 - \phi s)/(w_2 - \phi s)$.

Define $t := (w_1 - \phi s)/(w_2 - \phi s)$, and then we have the following lemma.

Lemma 1. *Assuming that when $t = t^*$, Π^{sc}_{qr} achieves its optimal value Π^{sc*}_{qr}, we have $t^* \in \left((c_1 - s)/(c_2 - s), 1\right]$.*

The lemma above specifies the interval for t^*. Only when t belongs to this set, will it be possible for the decentralized system with quick response to attain its optimal profits. From Proposition 3, we know $\overline{G}\left(q_{qr}\right) = t$. Since the retailer determines the initial stocking level according to the terms in the revenue-sharing contract (w_1, w_2, ϕ), Lemma 1 provides guidance on how to set the parameters in the contract, which leads to optimal profits for the decentralized supply chain.

When $\phi = 1$, the revenue-sharing contract (w_1, w_2, ϕ) is simplified to a two-stage wholesale price contract (w_1, w_2). Thus we have the following proposition.

Proposition 4. Suppose that under the two-stage wholesale price contract $\left(w_1^*, w_2^*\right)$, the supply chain attains its optimal profits; that is $\left(w_1^* - s\right)/\left(w_2^* - s\right) = t^*$. We use ϕ^{**} to denote the retailer's profit share under this contract. One sufficient condition for the supply chain under revenue-sharing contracts (w_1, w_2, ϕ) to achieve its optimal profits is

$$\begin{cases} w_1 = \phi w_1^*, \\ w_2 = \phi w_2^*. \end{cases}$$

In addition, the retailer's share of the overall supply chain profits is $\phi\phi^{**}$, and the manufacturer's share is $1 - \phi\phi^{**}$.

Like the revenue-sharing contract in the supply chain without quick response, the contract here also imposes an upper bound on the retailer's profit share, since $\phi \in (0, 1]$. The upper bound ϕ^{**} is borrowed from the retailer's profit share under the two-stage wholesale price contract, indicating that the retailer would usually have a smaller profit share under the revenue-sharing contract than under the wholesale price contract. In a decentralized supply chain dominated by the manufacturer, revenue-sharing contracts work very well to align the manufacturer's interest with the interest of the supply chain as a whole. As a result, the manufacturer earns satisfactory profits when the supply chain achieves optimal profits.

5. Centralized supply chain

This section introduces the model of centralized supply chains. In previous sections, the manufacturer sells products to consumers through the retailer under revenue-sharing contracts. We interpret the model as the decentralized supply chain model. In this section, a firm manufactures products itself and sells directly to its consumers. Therefore, a centralized supply chain consists of a single firm and a mass of strategic customers. Other assumptions about the firm and customers are adopted from the model in previous sections. The centralized supply chain model here resembles the classic newsvendor model [48] taking strategic customer behavior into consideration.

First, we investigate the inventory decision of a firm without quick response. The production lead time is so long that the firm has to determine its inventory well in advance of the selling season. We use the subscript c to denote "centralized supply chain" where necessary. According to Proposition 1, the optimal full price is now

$$p_c = s + \sqrt{(c-s)(v-s)}, \tag{10}$$

and the optimal inventory of the firm is now

$$\overline{G}(q_c) = \sqrt{\frac{c-s}{v-s}}. \tag{11}$$

These two equations are proposed in Ref. [14].

Now we turn to the decision of a firm with quick response capability. In addition to its original production before the season, it is able to produce additional units at the beginning of the full price period to satisfy the demand. In what follows, the subscript cqr stands for "centralized supply chain with quick response". It follows from Proposition 3 that the optimal initial inventory of the firm is

$$\overline{G}\left(q_{cqr}\right) = \frac{c_1 - s}{c_2 - s}. \tag{12}$$

Cachon and Swinney [36] derive a similar result for the quick response system in terms of the full price. Moreover, they demonstrate that the full price in the centralized supply chain is higher with quick response than without. Yet our result given by (12) is characterized in terms of quantity. For the firm with quick response capability, initial inventory is related to the ordinary product cost as well as the quick response product cost.

6. Supply chain performance and value of quick response

Here we compare the four supply chains in terms of inventory and performance, and then investigate the value of quick response in alternative systems.

6.1. Inventory and supply chain performance

This subsection studies the optimal profits in different supply chain systems, along with the optimal inventory quantities. We consider the four systems described above: the centralized supply chain, the centralized supply chain with quick response, the decentralized supply chain, and the decentralized supply chain with quick response. We suppose that $c = c_1$, thereby having the following proposition.

Proposition 5. (i) The optimal initial inventory level is lower in the decentralized supply chain with quick response than in the centralized supply chain with quick response, which has lower optimal inventory level than the centralized supply chain without quick response; that is to say, $q_{qr}^{*} < q_{cqr} < q_c$.

(ii) The decentralized supply chain with quick response has the highest profits among the four kinds of systems, while the centralized supply chain without quick response has the lowest profits; that is $\Pi_c^{sc} < \Pi_{cqr}^{sc} < \Pi_{qr}^{sc*}$, and $\Pi_c^{sc} \le \Pi_s^{sc*} < \Pi_{qr}^{sc*}$.

After adopting quick response, the firm in the centralized system lowers its initial inventory, which reduces the likelihood for a strategic consumer to acquire a product at a salvage price. Furthermore, the stocking level is lower in the decentralized system with quick response than in the centralized system, regardless of whether or not the latter adopts quick response. Accordingly, the retailer in the decentralized supply chain could charge a higher price in the first period, leading to profit increment for the supply chain.

The value of quick response capability proves to be positive in both centralized systems and decentralized systems. With strategic customers, both the centralized supply chain and the decentralized supply chain achieve more profits with quick response than without, although the extra cost of quick response may be high. Despite the investment required, quick response is valuable and increases the profits of supply chains under certain conditions.

Both decentralization and quick response contribute to incremental profits of the whole supply chain. Conventional supply chain management theory generally states that double marginalization in a decentralized supply chain may harm the efficiency of the supply chain. Nonetheless, Su and Zhang [14] discover that double marginalization might benefit a decentralized supply chain with strategic customer behavior. The centralized supply chain has lower profits than the decentralized supply chain because of strategic customer behavior. In the centralized system, the firm has to set a relatively low price in the first period to induce strategic consumers to purchase early. In the decentralized system, the retailer reduces its stocking quantity due to double marginalization, leading to higher risk of stockout faced by a strategic consumer who delays the purchase. Hence, the payoff from waiting for the sale falls, thereby increasing strategic customers' willingness to purchase immediately. So in the first period, the retailer here could charge a substantially higher price than the firm in the centralized system. As a result, the overall profits of the decentralized supply chain exceed the profits of the centralized supply chain. On the basis of [14], we consider the impact of quick response on supply chain performance. We find that the decentralized supply chain could further enhance its performance by building quick response capability. Moreover, the centralized supply chain with quick response could also attain more profits by decentralizing.

6.2. Value of quick response

This subsection compares the value of quick response in centralized supply chains with that in decentralized supply chains. In the above subsection, we demonstrate that quick response provides value in both the centralized supply chain and the decentralized supply chain. Then, one would ask: which system (centralized supply chain or decentralized supply chain) could achieve larger profit increment when implementing quick response? Su and Zhang [14] state that decentralization could be beneficial for a supply chain facing strategic customers. Cachon and Swinney [9] find that consumers' strategic behavior could enhance the value of quick response. Based on these results, an intuitive answer would be that with strategic customers, quick response should add more value to the decentralized supply chain than to the centralized supply chain. Here we investigate whether this intuition is right.

The value of quick response is characterized as the profit increment for a supply chain implementing quick response. In other words, the value of quick response in the centralized system is given by $\Delta_c = \Pi^{sc}_{cqr} - \Pi^{sc}_{c}$, while the value of quick response in the decentralized supply chain is given by $\Delta = \Pi^{sc*}_{qr} - \Pi^{sc*}_{s}$. The following proposition compares the value of quick response in the centralized supply chain with that in the decentralized supply chain. We assume that the centralized supply chain system is under the control of a core member who is aware of strategic consumer behavior. By deciding all the variables that the system is able to determine, the core member endeavors to optimize the overall performance of the centralized supply chain.

Proposition 6. Assume that the manufacturer and the retailer in the decentralized supply chain agree to revenue-sharing contracts.

(i) There exists some $c_l \in (c_1, p_c)$ such that for $c_2 \in (c_1, c_l)$, the value of quick response in the centralized system exceeds the value in the decentralized system; that is to say, $\Delta_c - \Delta \geq 0$ for $c_2 \in (c_1, c_l)$.
(ii) There exists some $c_h \in (c_l, p_c)$ such that for $c_2 \in (c_h, p^*_s)$, the value of quick response is strictly higher in the decentralized system than in the centralized system; that is to say, $\Delta - \Delta_c > 0$ for $c_2 \in (c_h, p^*_s)$.

The result in part (i) of Proposition 6 is surprising: adopting quick response could bring more incremental profits to the centralized supply chain than to the decentralized supply chain, as long as the extra cost of quick response is low. It is in contrast to the intuition stated above. The key to this result lies in the fact that with quick response, centralized systems and decentralized systems have exactly the same upper bound on profits. When the unit cost of the second procurement is close to the unit cost of the first order, both systems almost reach the same upper bound; in other words, the profits of the centralized systems are quite close to the profits of the decentralized system in this case. On the other hand, without quick response, the decentralized system could attain higher profits than the centralized one. As a result, the value of quick response is higher in the centralized supply chain than in the decentralized supply chain, provided that each unit with quick response doesn't cost far more than the unit cost of ordinary products.

On the other hand, if the extra cost of quick response is high, quick response generates greater value for decentralized supply chains than for centralized supply chains, as shown in part (ii) of Proposition 6. Let's consider an extreme case here. When the unit cost of the second procurement exceeds the full price in the centralized system, the firm would find it unprofitable to submit a second order, even if the firm has the option. Thus the profits in the centralized supply chain with quick response coincide with the profits in the centralized supply chain. In this situation, however, the retailer in the decentralized system with quick response would still make an additional procurement, for the full price is higher in the decentralized system than in the centralized one. Therefore, the value of quick response is positive in the decentralized supply chain, while it is negligible in the centralized supply chain. In fact, however, it would be more reasonable to examine the case when the unit cost of the second procurement is lower than the full price in the centralized supply chain. Indeed, Proposition 6(ii) also demonstrates that there exist situations in which the value of quick response is higher in the decentralized system when the unit cost of the second order is lower than the full price in the centralized system. For more discussion, see the following section, which shows that the value of quick response falls more sharply in the centralized system than in the decentralized system as the unit cost rises.

7. Numerical study

In this section, we conduct a numerical study to analyze the value of quick response in various supply chain settings. Since the equilibrium expressions of the profits are complex, it is quite difficult to explore the magnitude of the value of quick response analytically. To test the *robustness* of our findings, we provide results not only under revenue-sharing contracts, but also under wholesale price contracts.

In the experiments, we use every possible combination of the parameters shown in Table 1, leading to 3000 examples in total. We adopt Gamma distribution to simulate customer demand, which is also used in Ref. [9]. There are six values for parameter c_2, determined in terms of c_1 and $(p_c - c_1)$; p_c is obtained using (10). When $c_2 = c_1 + 0.01(p_c - c_1)$, c_2 is quite close to c_1; by contrast, c_2 is much larger than c_1 and nearly reaches p_c, when $c_2 = c_1 + 0.99(p_c - c_1)$.

As for the parameter w in the decentralized supply chain without quick response, there are five values. Recall that Proposition 6 is derived under the assumption that the decentralized supply chain implements revenue-sharing contracts. If a revenue-sharing contract is adopted, the supply chain would set $w = w^*_s$, in which w^*_s is the optimal wholesale price in the contract. So, the first value in our experiments for w is w^*_s. As the optimal profits of the whole supply chain remain constant while the share ϕ varies, we do not explicitly consider ϕ here. Moreover, we also consider the scenarios where wholesale price contracts are implemented. In such situations, the manufacturer and the retailer might not agree to set $w = w^*$, due to their individual interests. Thus, the other four values of w are given in terms of c_1 and $(v - c_1)$.

Correspondingly, in the decentralized supply chain with quick response, there are five combinations of w_1 and w_2. Under revenue-sharing contracts, the combination of w_1 and w_2 is set to achieve the optimal profits of the system. Like the profits of the above decentralized system without quick response, the overall profits of the system with quick response are also independent of ϕ, so here the retailer's share of the realized revenue is not explicitly studied either. Under wholesale price contracts, the four combinations of (w_1, w_2) are determined through the following two steps. (1) The four values of w_1 equal the four values of w in the above decentralized supply chains without quick response, respectively. (2) On the basis of the four values of w_1, the four values of w_2 are derived by maximizing the profits of the decentralized supply chains with quick response, respectively; that is to say, given a particular w_1, each w_2 is selected to optimize the profits of the decentralized system.

7.1. Impact of the cost variation on relative values

The results of the experiments under revenue-sharing contracts are presented in Table 2. The table reveals the mean values of Δ_c/Δ decrease in c_2. Recall that $\Delta_c = \Pi^{sc}_{cqr} - \Pi^{sc}_{c}$ and $\Delta = \Pi^{sc*}_{qr} - \Pi^{sc*}_{s}$. When c_2 is low relatively, quick response provides more value for centralized systems than for decentralized systems. For example, all the mean values of Δ_c/Δ are larger than 1 when $(c_2 - c_1)/(p_c - c_1) = 0.01$. It helps to demonstrate Proposition 6(i). But when $c_2 \in \{c_1 + 0.8(p_c - c_1),\ c_1 + 0.99(p_c - c_1)\}$, the value of quick response is higher in decentralized supply chains, as opposed to in centralized supply chains. This is consistent with part (ii) of Proposition 6. Particularly, the maximum value of Δ_c/Δ

Table 1
Parameter values used in numerical examples.

Parameter	Values
Demand distribution	Gamma
μ	100
σ	{10, 30, 50, 70, 90}
v	10
c_1	{2, 3, 4, 5, 6}
c_2	$\{c_1+0.01(p_c-c_1),\ c_1+0.2(p_c-c_1),\ c_1+0.4(p_c-c_1), c_1+0.6(p_c-c_1),\ c_1+0.8(p_c-c_1),\ c_1+0.99(p_c-c_1)\}$
w	$\{w_s^*,\ c_1+0.2(v-c_1),\ c_1+0.4(v-c_1),\ c_1+0.6(v-c_1),\ c_1+0.8(v-c_1)\}$
s	$\{0.2c_1,\ 0.4c_1,\ 0.6c_1,\ 0.8c_1\}$

Table 2
Relative values (Δ_c/Δ) under revenue-sharing contracts.

Parameters σ/μ	Mean value of Δ_c/Δ $(c_2-c_1)/(p_c-c_1)$						Maximum value of Δ_c/Δ	Minimum value of Δ_c/Δ
	0.01	0.2	0.4	0.6	0.8	0.99		
0.1	3.260	2.316	1.607	1.029	0.509	0.026	3.882	0.012
0.3	1.636	1.174	0.826	0.537	0.270	0.014	1.886	0.006
0.5	1.297	0.936	0.664	0.436	0.222	0.012	1.449	0.005
0.7	1.157	0.836	0.594	0.391	0.200	0.011	1.257	0.004
0.9	1.085	0.786	0.557	0.365	0.185	0.010	1.153	0.004
All	1.687	1.210	0.850	0.552	0.277	0.015	3.882	0.004

Table 3
Relative values (Δ_c/Δ) under wholesale price contracts.

Parameters σ/μ	Mean value of Δ_c/Δ $(c_2-c_1)/(p_c-c_1)$						Maximum value of Δ_c/Δ	Minimum value of Δ_c/Δ
	0.01	0.2	0.4	0.6	0.8	0.99		
(a) When $w=c_1+0.2(v-c_1)$								
0.1	1.302	0.882	0.579	0.353	0.179	0.010	1.419	0.004
0.3	1.223	0.860	0.590	0.374	0.192	0.010	1.340	0.004
0.5	1.161	0.831	0.583	0.380	0.200	0.011	1.265	0.004
0.7	1.112	0.801	0.567	0.375	0.202	0.012	1.197	0.004
0.9	1.073	0.776	0.550	0.366	0.201	0.012	1.139	0.004
All	1.174	0.830	0.574	0.370	0.195	0.011	1.419	0.004
(b) When $w=c_1+0.4(v-c_1)$								
0.1	1.719	1.175	0.779	0.474	0.221	0.011	1.959	0.005
0.3	1.443	1.025	0.711	0.455	0.225	0.011	1.642	0.005
0.5	1.270	0.915	0.647	0.423	0.215	0.011	1.418	0.005
0.7	1.156	0.836	0.594	0.391	0.200	0.011	1.257	0.004
0.9	1.081	0.782	0.555	0.363	0.184	0.010	1.143	0.004
All	1.334	0.947	0.657	0.421	0.209	0.011	1.959	0.004
(c) When $w=c_1+0.6(v-c_1)$								
0.1	2.289	1.585	1.068	0.661	0.314	0.015	2.682	0.007
0.3	1.602	1.147	0.805	0.522	0.261	0.013	1.849	0.006
0.5	1.294	0.934	0.662	0.435	0.221	0.012	1.442	0.005
0.7	1.130	0.816	0.579	0.380	0.194	0.010	1.213	0.004
0.9	1.040	0.752	0.531	0.347	0.175	0.009	1.076	0.003
All	1.471	1.047	0.729	0.469	0.233	0.012	2.682	0.003
(d) When $w=c_1+0.8(v-c_1)$								
0.1	3.002	2.117	1.457	0.924	0.451	0.023	3.579	0.011
0.3	1.615	1.158	0.814	0.528	0.265	0.014	1.852	0.006
0.5	1.213	0.872	0.614	0.400	0.202	0.010	1.327	0.004
0.7	1.044	0.751	0.529	0.344	0.174	0.009	1.093	0.003
0.9	0.969	0.698	0.491	0.319	0.160	0.008	0.978	0.003
All	1.569	1.119	0.781	0.503	0.250	0.013	3.579	0.003

reaches 3.882, while the minimum value of Δ_c/Δ attains 0.004. Notice that as c_2 approaches p_c from below, Δ_c approaches 0 while Δ is substantially above zero. As a result, when $(c_2-c_1)/(p_c-c_1)=0.99$, Δ_c/Δ almost drops to zero.

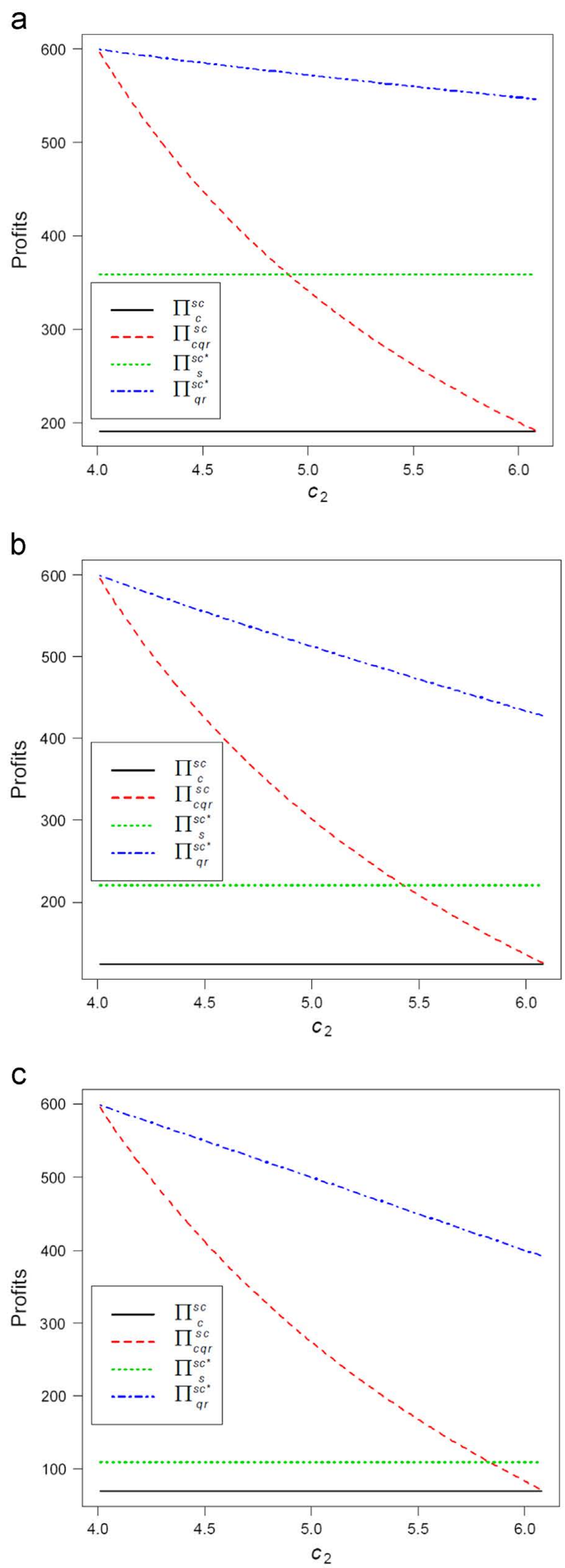

Fig. 3. An example of the profits of the four supply chains with $v=10$, $c_1=4$, $s=0.4c_1$, and $w=c_1+0.4(v-c_1)$, when $\sigma/\mu=0.1$ (a), $\sigma/\mu=0.5$ (b), and $\sigma/\mu=0.9$ (c).

Table 3 shows the results when decentralized supply chains are governed by wholesale price contracts. The table here also reveals that if c_2 is near c_1, quick response could be more valuable in

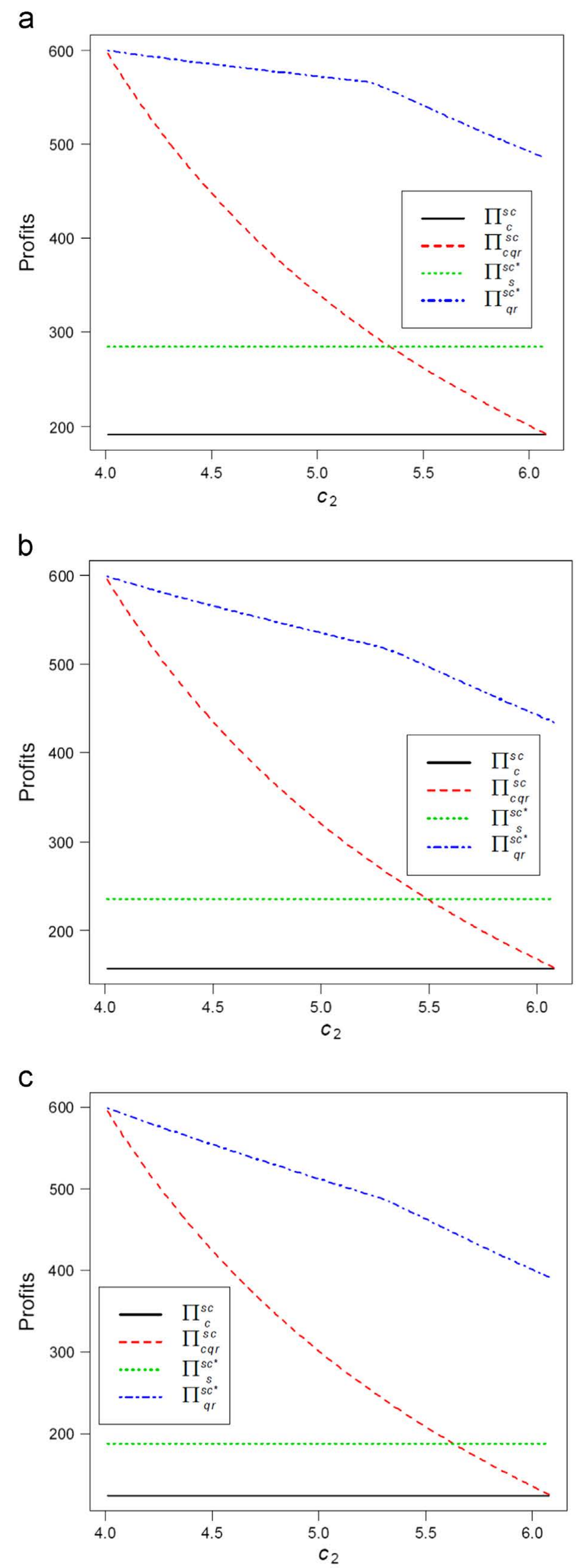

Fig. 4. An example of the profits of the four supply chains with $v=10$, $c_1=4$, $s=0.4c_1$, and $w=c_1+0.2(v-c_1)$, when $\sigma/\mu=0.1$ (a), $\sigma/\mu=0.3$ (b), and $\sigma/\mu=0.5$ (c).

centralized systems, compared to in decentralized systems. When c_2 is much larger than c_1, quick response adds more value to decentralized systems than to centralized systems. Therefore, Proposition 6 is quite robust to alternative contractual formats.

7.2. Impact of demand uncertainty on relative values

We find that as in Table 2, mean values of Δ_c/Δ decrease in general as demand uncertainty, represented by coefficient of variations (σ/μ), increases. This is mainly because the profits of the decentralized supply chains (Π_s^{sc*}) fall faster than the profits of the centralized supply chains (Π_c^{sc}) as demand uncertainty rises. To illustrate, Fig. 3 depicts the profits of each of the various systems against c_2, when $w = c_1 + 0.4(v - c_1)$. The figure shows as σ/μ increases from 0.1 to 0.9, Π_s^{sc*} drops more sharply than Π_c^{sc}, resulting in a decline in Δ_c/Δ overall.

However, there are exceptions in Table 3. Mean values of Δ_c/Δ climb as demand uncertainty increases, when $(c_2 - c_1)/(p_c - c_1) = 0.99$ in Table 3(a). The mean values first rise and then fall, as σ/μ increases, when $0.4 \le (c_2 - c_1)/(p_c - c_1) \le 0.8$ in Table 3(a); so do the mean values in Table 3(b), when $(c_2 - c_1)/(p_c - c_1) = 0.8$. In many of these scenarios, $w_1 < c_2$. Notice that the wholesale price contract could be treated as a particular version of the revenue-sharing contract by setting $\phi = 1$. Because here $c_2 \le w_2$, when $w_1 < c_2$, we have $(w_1 - s)/(w_2 - s) \le (w_1 - s)/(c_2 - s) < 1$. As a result, $(w_1 - s)/(w_2 - s)$ may not be able to reach t^*, which leads to the optimal profits for the quick response supply chain under wholesale price contracts, according to Lemma 1 and Proposition 4. Property of the mean value of Δ_c/Δ is thus affected. Fig. 4 illustrates the profits of the four systems when $w = c_1 + 0.2(v - c_1)$, from which we can derive relative values (Δ_c/Δ); e.g., when $c_2 = 0.8(p_c - c_1) + c_1 = 5.67$, the relative values obtained are 0.203 (a), 0.218 (b), and 0.227 (c).

8. Discussion, extension and managerial implications

8.1. Adoption of revenue-sharing contracts

In previous sections, we make the assumption that revenue-sharing contracts (w, ϕ) are adopted in decentralized supply chain systems. Here we discuss the reasons for employing revenue-sharing contracts.

Revenue-sharing contracts are closely related to franchise agreements accepted by firms in the apparel industry. A company selecting decentralized supply chain structure usually signs franchise agreements with its partner. Although franchise agreements could vary a lot in franchise systems, franchisors routinely request their franchisees to pay royalties [49]; e.g., Gap, a US-based apparel giant, receives royalties from franchisees in addition to payments for the merchandise [50]. Furthermore, the royalty is typically paid as a percentage of franchisee sales [49]. For example, New Look, a leading fast fashion company headquartered in the UK, sells products to its franchisees at low prices and then collects royalties based on franchisee sales [51]. Express, an American apparel and accessory retailer, also asks its franchisees to pay royalties tied to their sales [52]. The royalty rate in franchise agreements resembles the manufacture's revenue share percentage in revenue-sharing contracts, so it is reasonable to believe that the results derived from our research with revenue-sharing contracts could help firms set the terms in franchise agreements.

Moreover, the findings with revenue-sharing contracts could provide valuable reference for supply chains employing wholesale price contracts as well. Note that a revenue-sharing contract is simplified to a wholesale price contract, if the retailer is allowed to keep all of its revenue generated from selling the products. Clearly, most of the results in our work would continue to hold under the wholesale price contract, though the contract only permits one particular split of total profits between members in the supply chain. Centralized systems would also gain more from implementing quick response than decentralized systems with wholesale price contracts, when the additional cost of the product with quick response is relatively low.

8.2. Allocation mechanism

Now we extend the analysis to consider a more general allocation rule in the salvage price period. Following the allocation mechanism in [9], we denote the strategic consumer's level of optimism by $\theta \in (0, 1]$, which relates to the probability that the consumer could receive a product at salvage price. Now the strategic consumer waiting for the sale would have to compete with bargain hunters for the product if the seller announces the beginning of the second period. As before, we suppose that the retailer sets the optimal price before the first period and all strategic consumers buy immediately in equilibrium. But if one single strategic customer chooses to delay the purchase, this consumer would be one of the $1/\theta$ customers who arrive earliest when the second period commences (the rest of the early arrivals are bargain hunters). Assume that the strategic consumer could be in any position in the early arrival sequence and the probability of being in each specific position is θ. Let φ denote the probability that the strategic customer could obtain *one unit* of the product at the salvage price. Because the seller marks down the price only if it has excess inventory, φ can be expressed as

$$\varphi = \int_0^q \{1 \wedge \theta[q - (a - 1)]\} g(a) da.$$

Therefore, the lower the θ, the less likely it is for the strategic consumer to get a product in the salvage price period. With the above φ, it is very difficult to study the value of quick response analytically, so we provide a numerical example in Fig. 5. The relative values (Δ_c/Δ) are derived when $\theta \in \{0.1, 0.2, 1\}$.

Fig. 5 shows that our results continue to hold when a strategic consumer does not have the highest priority to obtain the product in the second period. The value of quick response is higher in centralized systems than in decentralized systems if the extra cost of quick response is relatively low, whereas decentralized supply chains reap more incremental profits from adopting quick response if the additional cost of quick response is high. As θ decreases from 1 to

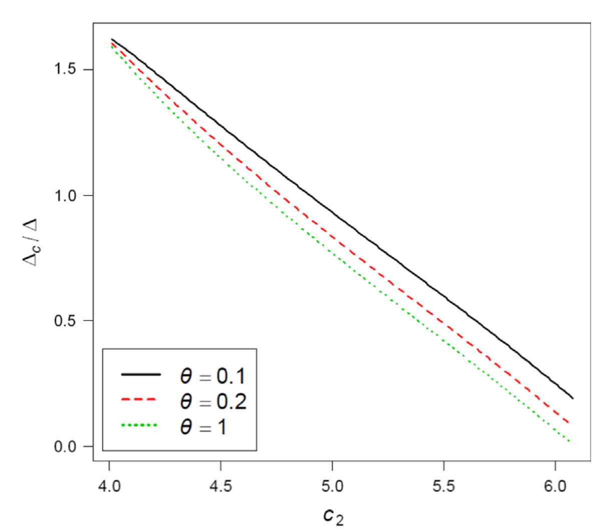

Fig. 5. An example of the relative values (Δ_c/Δ) with $v = 10$, $c_1 = 4$, $s = 0.4c_1$, and demand Gamma distributed with mean 100 and standard deviation 30.

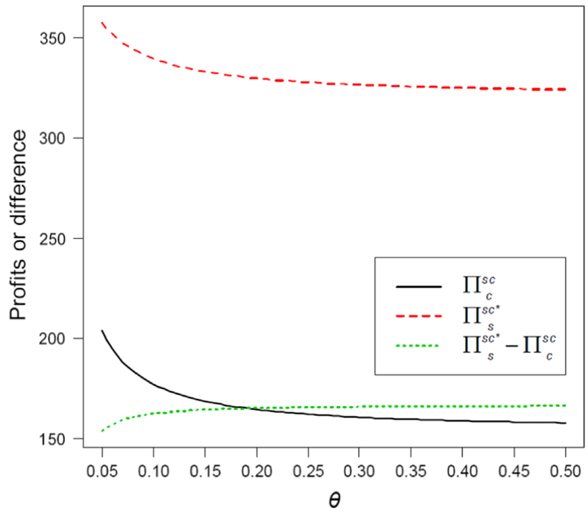

Fig. 6. An example of the profits (or the difference) with $v=10$, $c_1=4$, $s=0.4c_1$, and demand Gamma distributed with mean 100 and standard deviation 30.

0.1, Δ_c/Δ increases a little. In other words, the relative value rises slightly as the strategic consumer's probability to acquire the product at salvage price decreases.

It is worthwhile to point out that the decentralized supply chain continues to outperform the centralized supply chain with the allocation rule above. Due to significant difficulty obtaining analytical results, here we also present a numerical example. Fig. 6 illustrates the profits of the centralized supply chain Π_c^{sc} and the profits of the decentralized supply chain Π_s^{sc*} as a function of θ, as well as the difference between Π_s^{sc*} and Π_c^{sc}. The figure reveals that as the competition between the strategic consumer waiting for the sale and bargain hunters intensifies, the difference falls slightly. However, the decentralized system has significantly higher profits relative to the centralized system, even if θ drops to 0.05.

8.3. Managerial implications

Here we present managerial implications, which would provide firms implementing quick response with reference on the choice of supply chain structure, the selection of appropriate contract, and the approach to better discourage strategic customer behavior.

First, centralized supply chains could take better advantage of quick response, relative to decentralized supply chains, if the extra cost of quick response is relatively low. We have shown that centralized systems would harvest more incremental benefits from adopting quick response, as long as the systems could effectively reduce the extra cost. This helps to justify the effort made by some firms with quick response to shorten their supply chains. Besides Zara, the canonical example of firms building vertically integrated supply chains, New Look also pays close attention to centralization of its supply chain, as it highlights its move to purchase its franchise business in Poland [51]. In fact, vertical integration has the potential for facilitating the implementation of quick response in a system, thereby bringing down the extra cost of quick response. This is because misaligned incentives of different parties within a long supply chain might hinder the adoption of quick response [38,39]. On the other hand, a firm operating a centralized system seldom worries about a problem like this. Therefore, it is likely that in companies like Zara [2,3], the cost of per unit with quick response would not be much higher than the unit cost of inventory prepared prior to the selling season.

Yet, firms with relatively high extra cost of quick response may employ decentralized supply chain structure. We have seen from Section 6.2 that the value of quick response is higher in decentralized supply chains than in centralized supply chains, when the unit cost of procurement with quick response is much higher than the unit cost of initial order, contributing to high profits of decentralized supply chains. This suggests that companies implementing quick response could construct decentralized supply chains, if the additional cost of quick response is relatively high. Indeed, decentralization is the exact approach taken by firms such as H&M [5] and Mango [8]. They either purchase merchandise from independent suppliers or sell products through franchisees to consumers, which could very well result in substantial incremental cost of quick response. In such situation, it is reasonable to believe that decentralized structure would be helpful in promoting the value of quick response.

As for the contracts, decentralized supply chains governed by wholesale price contracts may consider replacing their contracts with revenue-sharing contracts. In Sections 3.4 and 4.2, we have seen that the revenue-sharing contract permits alternative allocations of overall profits between supply chain members, as well as enabling a decentralized supply chain to perform better than a centralized supply chain, though the retailer' share of profits in the decentralized supply chain is limited. Chances are revenue-sharing contracts would be welcome in a supply chain system dominated by the manufacturer. In reality, revenue-sharing contracts are observed in franchise agreements adopted in the apparel industry [51,52]. In these cases, franchisors are often more powerful than franchisees in the supply chains. Therefore, the adoption of revenue-sharing contracts in these supply chains should be smooth, thereby enhancing the overall profits of the supply chains.

Finally, companies facing strategic consumers should lower their initial inventory accordingly, when implementing quick response. Otherwise, they would not be able to make the best of quick response. We have shown that a firm with quick response should effectively reduce its inventory prepared before the selling season. Nevertheless, due to human bias or many complex factors of the system, the firm might stick to its historical inventory decision or fail to reduce the stocking quantity sufficiently. Consequently, the company would not be able to discourage strategic customer behavior to a large extent since it still offers discounts too often, thought it could completely meet the aggregate demand over the selling season because of quick response. In particular, retailers in decentralized supply chains might even fail to realize that they should lower the initial stocking levels, for the inventory is smaller in decentralized systems than in centralized systems before quick response is adopted. For these firms, lowering the initial inventory would not hurt the profits. Instead, it would enhance the profits.

9. Conclusion

This paper considers the intersection of supply chain management in operations management and consumer behavior in marketing. By studying the performance of various supply chains with strategic customer behavior, we compare the value of quick response in decentralized systems with that in centralized systems. Parties in the decentralized systems agree to revenue-sharing contracts.

Our finding deepens our understanding of revenue-sharing contracts. As a device to facilitate the achievement of the optimal equilibrium profits, the revenue-sharing contract is superior to the wholesale price contract. It supports alternative allocations of profits, thus better ensuring that the optimal profits of the decentralized system can be achieved, provided that the bargaining power of the retailer changes within a certain range. However, the revenue-sharing contract here fails to provide sufficient flexibility to arbitrarily divide the total profits between parties within the system. Researchers have shown that revenue-sharing contracts permit any allocation of the overall profits [15], but we present a different view that with strategic customer behavior, revenue-sharing contracts only have limited flexibility.

Our work also sheds light on how the choice of supply chain structures influences the value of quick response. Quick response is adopted by many firms in the apparel industry. These firms need to determine their supply chain structures to take full advantage of quick response. We discover there is an upper bound on profits that the supply chain can attain. With strategic customer behavior, both quick response and decentralization allow supply chains to move closer to the upper bound. Furthermore, the centralized system and the decentralized system have the same upper bound. As a result, the value of quick response would be greater in centralized systems than in decentralized systems if the additional cost of quick response is low. When the cost of per unit with quick response is close to the cost of an ordinary product, supply chains with quick response, both centralized and decentralized, nearly attain the upper bound of profits. Since decentralized systems are already closer to the upper bound than centralized systems, the latter could very well harvest more benefits from quick response.

Our findings of quick response provide valuable reference on real world practice for firms. These days, consumers behave more strategically with the assistance of new information technology. As the competition between firms becomes increasingly intense, managers have to decide whether to invest in developing quick response capability or not. When making such decisions, they should be aware that the value of quick response depends not only on the extra cost of quick response, but also on the structure of their systems.

As for future research, we have the following recommendations. First, our work could be extended by investigating dual-channel supply chain structure. The online channel has become increasingly important for firms. Many retailers in the apparel industry sell fashions not only in brick-and-mortar stores, but also through online operations. Meanwhile, Strategic consumers could benefit from choosing the proper channel for shopping. Second, Future research may analyze the impact of adopting quick response on supply chain competition with strategic customer behavior. In reality, the rivalry between firms is gradually replaced by the competition between supply chains. A firm usually joins a supply chain to take part in the horizontal supply chain competition. Third, it would be interesting to study how other behavior regularities of consumers influence the value of quick response. Our model is confined to strategic customer behavior. Beside strategic behavior, other behavior regularities also impact consumers' purchase decisions. Therefore incorporating customer disappointment aversion [33], reference price effect [53], or consumer inertia [31] is a promising area for future work.

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Appendix

Proof of Proposition 1. From Eq. (2), we derive

$$\frac{\partial \Pi_s^j}{\partial q} = \phi(p-s)\overline{G}(q) - (w-\phi s). \Rightarrow \frac{\partial^2 \Pi_s^j}{\partial q^2} = \phi(p-s)(-g(q)).$$

Since $g(a) > 0$, it's obvious that $\partial^2 \Pi_s^j / \partial q^2 < 0$. Given a particular p, the profit function Π_s^j defined in (2) is concave in q. It follows from $\partial \Pi_s^j / \partial q = 0$ that

$$\overline{G}(q) = \frac{w-\phi s}{\phi(p-s)}. \quad (13)$$

By (1),

$$p = s + (v-s)\overline{G}(q). \quad (14)$$

In equilibrium, all strategic customers purchase now according to REH. The result in Proposition 1 follows from combining (13) with (14).

Proof of Proposition 2. Since $q_s^* = Q_q^*$ and $\overline{G}\left(Q_q^*\right) = \sqrt{(w^*-s)/(v-s)}$, it follows from formula (3) that

$$\sqrt{\frac{w_s^*-\phi s}{\phi(v-s)}} = \sqrt{\frac{w^*-s}{v-s}} \Rightarrow w_s^* = \phi w^*.$$

When $w_s^* = \phi w^*$, combining (2) with (3) yields

$$\begin{aligned}\Pi_s^j &= \phi\left[(p_s-s)E(a \wedge q_s) + sq_s\right] - \phi w^* q_s \\ &= \phi\phi^* \Pi_q^*,\end{aligned}$$

and substituting (3) into (4) yields

$$\begin{aligned}\Pi_s^m &= (\phi w^* - c)q_s + (1-\phi)\left[(p_s-s)E(a \wedge q_s) + sq_s\right] \\ &= (w^*-c)q_s + (1-\phi)\left[(p_s-s)E(a \wedge q_s) - (w^*-s)q_s\right] \\ &= (1-\phi\phi^*)\Pi_q^*.\end{aligned}$$

Thus, the overall profit of the supply chain is Π_q^*, and we have the retailer's profit share as well as the manufacturer's profit share.

Proof of Proposition 3. The profit of the retailer with quick response is obtained using expression (6) as

$$\begin{aligned}\Pi_{qr}^j(q,p) &= (\phi p - \phi s)E(a \wedge q) - (w_1 - \phi s)q \\ &+ [(\phi p - \phi s) - (w_2 - \phi s)] \int_q^{+\infty} (a-q)g(a)da \\ &= \phi(p-s)E(A) - (w_1-\phi s)q - (w_2-\phi s)\int_q^{+\infty}(a-q)g(a)da. \quad (15)\end{aligned}$$

Thus, we have

$$\frac{\partial \Pi_{qr}^j}{\partial q} = -(w_1-\phi s) + (w_2-\phi s)\overline{G}(q). \Rightarrow \frac{\partial^2 \Pi_{qr}^j}{\partial q^2} = -(w_2-\phi s)g(q) < 0.$$

Therefore, the profit function Π_{qr}^j is concave in q, and then we have

$$\frac{\partial \Pi_{qr}^j}{\partial q} = 0 \Rightarrow \overline{G}\left(q_{qr}\right) = \frac{w_1-\phi s}{w_2-\phi s}.$$

Proof **of** Lemma 1. Combining (15) with (9) yields

$$\begin{aligned}\Pi_{qr}^m &= (w_1-c_1)q + (w_2-c_2)\int_q^{+\infty}(a-q)g(a)da \\ &+ (1-\phi)[(p-s)E(A) + sq] + (1-\phi)s\int_q^{+\infty}(a-q)g(a)da. \quad (16)\end{aligned}$$

Since here $p = s + (v-s)(w_1-\phi s)/(w_2-\phi s)$, adding the manufacturer's profits and the retailer's profits together yields the total profits of the supply chain

$$\Pi_{qr}^{sc} = (v-s)\tfrac{w_1-\phi s}{w_2-\phi s}E(A) - \left[(c_1-s)q + (c_2-s)\textstyle\int_q^{+\infty}(a-q)g(a)da\right].$$

$$\Rightarrow \Pi_{qr}^{sc} = (v-s)tE(A) - \left[(c_1-s)q + (c_2-s)\int_q^{+\infty}(a-q)g(a)da\right]. \quad (17)$$

Consider q as a function of t. Recall that $t = (w_1-\phi s)/(w_2-\phi s)$. Then we have the following formula via differentiation of multivariate composite function.

$$\frac{\partial \Pi_{qr}^{sc}}{\partial t} = \frac{d\Pi_{qr}^{sc}}{dt} + \frac{\partial \Pi_{qr}^{sc}}{\partial q} \cdot \frac{\partial q}{\partial t}. \tag{18}$$

It follows from (17) that

$$\frac{\partial \Pi_{qr}^{sc}}{\partial q} = -\left[(c_1 - s) - (c_2 - s)\overline{G}(q)\right] = -\left[(c_1 - s) - (c_2 - s)\frac{w_1 - \phi s}{w_2 - \phi s}\right]. \tag{19}$$

Since $1 - G(q) = t$, we define $L(q,t) = G(q) + t - 1$. Then we have the following equation through implicit differentiation.

$$\frac{\partial q}{\partial t} = -\frac{L_t'(q,t)}{L_q'(q,t)} = -\frac{1}{g(q)}. \tag{20}$$

According to (18)–(20), we have

$$\frac{\partial \Pi_{qr}^{sc}}{\partial t} = (v - s)E(A) + \frac{1}{g(q)}\left[(c_1 - s) - (c_2 - s)\frac{w_1 - \phi s}{w_2 - \phi s}\right]. \tag{21}$$

If $(w_1 - \phi s)/(w_2 - \phi s) \le (c_1 - s)/(c_2 - s)$, we get

$\frac{\partial \Pi_{qr}^{sc}}{\partial t} \ge (v - s)E(A) > 0.$

$$\Rightarrow t^* \in \left(\frac{c_1 - s}{c_2 - s}, 1\right]. \tag{22}$$

On the other hand, if $(w_1 - \phi s)/(w_2 - \phi s) > (c_1 - s)/(c_2 - s)$, it is straightforward to see that $t^* \in \left((c_1 - s)/(c_2 - s,)1\right]$ from the above expressions.

Proof of Proposition 4. When $w_1 = \phi w_1^*$ and $w_2 = \phi w_2^*$, it follows from (8) that

$$\overline{G}\left(q_{qr}\right) = \frac{w_1 - \phi s}{w_2 - \phi s} = \frac{\phi w_1^* - \phi s}{\phi w_2^* - \phi s} = \frac{w_1^* - s}{w_2^* - s} = t^*.$$

Therefore, the supply chain attains its optimal profits under the revenue-sharing contract $(\phi w_1^*, \phi w_2^*, \phi)$. Substituting the parameters in the contract into (6) yields the retailer's profits

$$\Pi_{qr}^{j}(q,p) = \phi[(p - s)E(a \wedge q) + sq] - \phi w_1^* q + (\phi p - \phi w_2^*)\int_q^{+\infty}(a - q)g(a)da$$
$$= \phi\left\{[(p - s)E(a \wedge q) + sq] - w_1^* q + (p - w_2^*)\int_q^{+\infty}(a - q)g(a)da\right\}.$$

Now it is quite easy to tell that the retailer's share of the total supply chain profit is $\phi\phi^{**}$. Consequently, the manufacturer's share is $1 - \phi\phi^{**}$.

Proof of Proposition 5. (i) According to (12), $\overline{G}\left(q_{cqr}\right)$ is decreasing in c_2. Therefore, it follows from (14) that p_{cqr} is decreasing in c_2. As c_2 approaches p_c, q_{cqr} and p_{cqr} approach q_c and p_c, respectively. Clearly, c_2 must satisfy the condition that $c_2 < p_c$ in the centralized supply chain with quick response, because otherwise the retailer would never submit a second order. It follows from Eq. (13) that $\overline{G}(q_c) = (c - s)/(p_c - s)$. Because $c = c_1$ and $c_2 < p_c$, comparing the above q_c to the q_{cqr} in (12) yields $q_{cqr} < q_c$. By Lemma 1, we have $(c_1 - s)/(c_2 - s) < \overline{G}\left(q_{qr}^*\right) \le 1$, leading to $q_{qr}^* < q_{cqr} < q_c$.

(ii) First, we prove $\Pi_c^{sc} < \Pi_{cqr}^{sc} < \Pi_{qr}^{sc*}$. According to (1) and (12), p_{cqr} is characterized as $p_{cqr} = v - (v - s)\left(1 - (c_1 - s)/(c_2 - s)\right)$. By (17), we have

$\Pi_{cqr}^{sc} = (v - s)\frac{c_1 - s}{c_2 - s}E(A) - \left[(c_1 - s)q + (c_2 - s)\int_q^{+\infty}(a - q)g(a)da\right].$

$$\Rightarrow \frac{d\Pi_{cqr}^{sc}}{dc_2} = -(v - s)(c_1 - s)E(A)(c_2 - s)^{-2} - \int_q^{+\infty}(a - q)g(a)da < 0. \tag{23}$$

Π_{cqr}^{sc} is thus decreasing in c_2. The profit of the centralized supply chain is obtained as

$$\Pi_c^{sc} = (v - s)\frac{c - s}{p - s}E(a \wedge q) - (c - s)q.$$

When c_2 approaches p, Π_{cqr}^{sc} approaches Π_c^{sc} correspondingly. Because $c_2 < p$ and Π_{cqr}^{sc} decreases in c_2, we have $\Pi_c^{sc} < \Pi_{cqr}^{sc}$. If $w_1 = c_1$ and $w_2 = c_2$, then $\Pi_{cqr}^{sc} = \Pi_{qr}^{sc}$ and $(w_1 - s)/(w_2 - s) = (c_1 - s)/(c_2 - s)$. By Lemma 1, we know that $\Pi_{cqr}^{sc} < \Pi_{qr}^{sc*}$. Consequently, $\Pi_c^{sc} < \Pi_{cqr}^{sc} < \Pi_{qr}^{sc*}$.

We next prove $\Pi_c^{sc} \le \Pi_s^{sc*} < \Pi_{qr}^{sc*}$. As stated in [13], without quick response capability, Π_q^* (the optimal profit of the decentralized supply chain under wholesale price contracts) is higher than Π_c^{sc} (the profit of the centralized supply chain). Proposition 2 shows that the supply chain attains the optimal profit Π_q^* under the revenue-sharing contract (w_s^*, ϕ) in which $w_s^* = \phi w^*$. Accordingly, $\Pi_c^{sc} \le \Pi_s^{sc*}$. In the decentralized supply chain under the revenue-sharing contract (w, ϕ), when $w = w_s^* = \phi w^*$, we have

$$p_s^* = s + \sqrt{(w^* - s)(v - s)}, \tag{24}$$

according to (3). It follows from (5) that

$$\Pi_s^{sc*} = (p_s^* - s)E(a \wedge q_s^*) - (c - s)q_s^*. \tag{25}$$

In the decentralized supply chain with quick response under the revenue-sharing contract (w_1, w_2, ϕ), by setting $w_1 = w_s^*$ and $w_2 = \phi p_s^*$, we get the profits of the supply chain

$$\Pi_{qr}^{sc'} = (p_s^* - s)E(a \wedge q_s^*) - (c - s)q_s^* + (p_s^* - c_2)\int_{q_s^*}^{+\infty}(a - q_s^*)g(a)da. \tag{26}$$

In the equation above, we implicitly assume that the retailer would submit a second order to satisfy all the unmet demand when the realized demand exceeds q_s^*, as long as its profits from the second order is nonnegative. According to (25) and (26),

$$\Pi_{qr}^{sc'} - \Pi_s^{sc*} = (p_s^* - c_2)\int_{q_s^*}^{+\infty}(a - q_s^*)g(a)da > 0,$$

because $c_2 < p_s^*$. It is obvious that $\Pi_{qr}^{sc*} \ge \Pi_{qr}^{sc'}$, so $\Pi_{qr}^{sc*} - \Pi_s^{sc*} \ge \Pi_{qr}^{sc'} - \Pi_s^{sc*} > 0$. Therefore, $\Pi_c^{sc} \le \Pi_s^{sc*} < \Pi_{qr}^{sc*}$.

Proof of Proposition 6. (i) According to (23), as c_2 approaches c_1 (recall that $c_2 > c_1$), Π_{cqr}^{sc} approaches $(v - c_1)E(A)$ correspondingly. By Lemma 1 and Eq. (17), as $c_2 \to c_1$, $\Pi_{qr}^{sc*} \to (v - c_1)E(A)$ as well. As stated in Proposition 5, $\Pi_{cqr}^{sc} < \Pi_{qr}^{sc*}$, so $\Delta_c - \Delta$ approaches $\Pi_s^{sc*} - \Pi_c^{sc}$ from below as $c_2 \to c_1$. By Proposition 5, we know $\Pi_s^{sc*} - \Pi_c^{sc} \ge 0$; in addition, $\Pi_s^{sc*} - \Pi_c^{sc}$ is independent of c_2. Therefore, $\Delta_c - \Delta \ge 0$ as $c_2 \to c_1$. Since $\Delta_c - \Delta$ is continuous, there exists some $c_l \in (c_1, p_c)$ such that for $c_2 \in (c_1, c_l)$, $\Delta_c - \Delta \ge 0$.

(ii) It is straightforward to tell that $p_s^* > p_c$, according to (24). As shown in Proposition 5, $\Pi_c^{sc} < \Pi_{cqr}^{sc}$ in centralized supply chains. As c_2 approaches p_c from below, we have $q_{cqr} \to q_c$ and $p_{cqr} \to p_c$. Thus, $\Pi_{cqr}^{sc} \to \Pi_c^{sc}$ as $c_2 \to p_c$. As a result, $\Delta - \Delta_c \to \Delta$ as $c_2 \to p_c$. Additionally, by Proposition 5, $\Pi_{qr}^{sc*} - \Pi_s^{sc*} > 0$. Since $\Delta = \Pi_{qr}^{sc*} - \Pi_s^{sc*}$, $\Delta - \Delta_c > 0$ as c_2 approaches p_c from below. As shown above, for $c_2 \in (c_1, c_l)$, $\Delta_c - \Delta \ge 0$; since $\Delta - \Delta_c$ is continuous, there exists some $c_h \in (c_l, p_c)$ such that for $c_2 \in (c_h, p_c)$, $\Delta - \Delta_c > 0$. When $p_c \le c_2 < p_s^*$, the retailer in the centralized supply chain with quick response would never submit a second order, so $\Delta_c = 0$ in this situation. However, $\Pi_{qr}^{sc*} > \Pi_s^{sc*}$ when $p_c \le c_2 < p_s^*$, so $\Delta - \Delta_c > 0$ for $c_2 \in [p_c, p_s^*)$. Therefore, there exists some $c_h \in (c_l, p_c)$ such that $\Delta - \Delta_c > 0$ for $c_2 \in (c_h, p_s^*)$.

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