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Channel incentives in sharing new product demand information and robust contracts

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ABSTRACT

Demand for a new product is often highly uncertain. As the developer of a new product, the manufacturer may reduce the uncertainty of the product's demand through observing progress in his product development process or receiving demand signals directly from customers. This paper first shows that a centralized channel always benefits from improved demand information. Yet, to realize this benefit in a decentralized manufacturer–retailer channel, the manufacturer needs to disclose his private demand information to the retailer. We show that the manufacturer's incentive to share his improved demand information depends on the supply contract signed with the retailer. Furthermore, mandating the manufacturer to disclose his improved demand information can actually reduce the total channel profit. We provide managerial insights by analyzing three widely used contract forms. We investigate whether these contracts are robust under an unanticipated demand information update observed by the manufacturer. We show that the quantity flexibility contract with a high return rate is not robust. The buyback contract, however, is robust and always achieves information sharing while preserving channel performance.

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1. Introduction

Consider a distribution channel with a manufacturer and a retailer. The manufacturer introduces a new product, and the retailer places orders to the manufacturer and stocks inventory to satisfy uncertain customer demand. The manufacturer and retailer sign a distribution contract long before the new product is introduced to consumers. For example, electronics manufacturers' often sign contracts with resellers a few quarters to a few years in advance. This time-window between contract signing and actual distribution is even longer for products with long life cycles such as automotive. During this time-window, the manufacturer prepares and improves production and distribution related processes. Similarly, the reseller uses this time-window to prepare its retail stores and train sales associates.[1] This time-window is often known as product and retail readiness. This paper considers the situation in which both firms share demand information at the beginning of this time-window and sign a contract. After signing the contract and during this time-window, the developer of the new product – the manufacturer – *may* obtain new demand information from sources that are not accessible to the retailer. At the time contract is signed, however, firms often do not anticipate and write a complex contract that consider various information update scenarios. Even when they do, the time-to-market pressure often requires firms to work with simple yet incomplete contracts (see, for example, Tirole, 1988 for several other reasons why firms sign incomplete contracts). Hence, this paper investigates whether widely used, simple contracts, such as price-only and buyback contracts, are *robust* under such information updates. More specifically, this paper investigates whether or not a *simple* contract, which is designed without anticipating a demand information update, can still induce firms to share the demand information update. To address this question, we also investigate when sharing this information is beneficial for both firms.

Demand information has been proven to be valuable in managing operations (e.g., Fisher and Raman, 1996; Iyer and Bergen, 1997). The manufacturer can perform market research on his product through focus groups and then update his demand information accordingly. For example, Apple Computers has been obtaining information from their user groups before introducing new products.[2] The company distributes prototypes to understand potential user preferences and demand. This way Apple Computers may obtain demand information that is not available to its retailers,

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[1] For an example of production readiness processes see Hitachi GST 2006 case study. For an example of retail readiness processes see Xbox game console retail agreements at http://www.xbox.com/en-US/retail/default.htm.

[2] http://www.apple.com/usergroups/.

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such as Bestbuy. Another example arises when the manufacturer uses a waterfall strategy. The manufacturer introduces the new product to different markets sequentially, sales data from the lead markets can give the manufacturer opportunities to update his demand information for successive markets (Kalish et al., 1995). We show that a centralized channel always benefits from improved demand information. Yet, to realize this benefit in a decentralized manufacturer–retailer channel, the manufacturer needs to disclose his private demand information to the retailer. We determine whether the manufacturer, after signing a supply contract, has an incentive to share his improved demand information with the retailer. We are primarily interested in how robust the supply contracts are under an unanticipated demand information update. In addition, we also investigate the impact of mandatory information disclosure on the total channel profit.

In practice, firms often prefer simple contracts that are easy to administer. Hence, commonly used contracts are observed to be simpler than theoretical predictions (Holmstrom and Milgrom, 1987). A contract is simple if it meets two criteria. First, the contract specifies few parameters, such as the price-only contract which stipulates a per-unit payment. Second, a contract is simple if it is state-independent and does not depend on various conditions. Hence, it does not have several "if" clauses. This may require a firm to design the contract based on simple scenarios and static information. In most cases, anticipating every possible contingency is also impossible and not practical. The firms cannot always identify every possible contingency in advance. Thus, they cannot write a complete contract that defines what to do in every possible contingency (incomplete contracts).[3] An ideal contract is a simple yet a robust contract that can keep the incentives aligned even in the face of an unpredicted change in the system after the contract terms are signed. This paper focuses on unanticipated demand information update that the manufacturer obtains and whether the contracts are robust when subject to this new information update.

The manufacturer's willingness to share his private information depends on his contractual relationship with the retailer. A contract that coordinates the channel initially might not preserve efficiency when demand information changes dynamically or unexpectedly, because it either cannot induce information sharing or generates a new distortion in the retailer's cost structure. Instead of designing incentive-compatible contracts, we focus on evaluating the performance of some widely used contract forms when information asymmetry emerges after contracting. Among the supply contract forms that we investigate, the buyback contract consistently eliminates information asymmetry and achieves the channel's first-best solution, but the price-only contract and the quantity flexibility contract behave differently.

We show that under a price-only contract the manufacturer does not have an incentive to share demand information when the channel's service level is high. Similarly, under a quantity flexibility contract the manufacturer does not have incentive to share information when the return ratio is high. We also show that when the manufacturer has no incentive for information sharing, mandating him to disclose his private information eliminates information asymmetry but results in lower channel profit. Furthermore, one would expect either a greater loss of sales under a price-only contract or larger excess inventory under a quantity flexibility contract. Hence, without aligning channel incentives, purely emphasizing information sharing could result in poor inventory decisions that lower the channel performance.

Both the buyback contract and the quantity flexibility contract offer the retailer return options; the former allows partial credit/full returns, while the latter allows full credit/partial returns. Pasternack (1985) has shown that both contract forms can coordinate a channel and allow the manufacturer and the retailer to divide the total channel profit arbitrarily. These contracts target the downside risk of the retailer by reducing her cost of overage. They do not change the retailer's underage cost. In other words, these two contracts are shown to be equivalent in several aspects (see Kaya and Özer, forthcoming). Our analysis, however, shows that these contracts perform differently when the manufacturer obtains an unanticipated demand information. We show that a buyback contract can always achieve information sharing; whereas a quantity flexibility contract cannot. While both a buyback contract and a quantity flexibility contract could achieve information sharing, the former can preserve its first-best performance, but the latter cannot.

2. Literature review

Firms can reduce demand uncertainty if they can collect demand related information and use this information in making inventory decisions. The benefit of improved demand information is often evaluated through a form of forecast updates. Fisher and Raman (1996) study the benefit of using early sales in demand forecasting. Iyer and Bergen (1997) examine the benefit of quick response through which one can shorten production lead time and hence obtain more time to collect demand related information. Gallego and Özer (2001) study the value of advance demand information. Chen (2001) shows that a company can gain advance demand information and hence improve profitability through offering incentives to customers who are willing to accept shipment delays. Using the convex ordering concept, we also evaluate the benefit of improved demand information. In addition, we consider the incentive issue in a decentralized manufacturer–retailer channel where the manufacturer observes the improved demand information. Our results demonstrate that better demand information cannot guarantee improved profitability for the whole channel.

The benefit of reducing demand uncertainty might not be realized in a decentralized channel because of incentive-misalignment problems. Channel inefficiency could exist because the transfer price generates distortion in the retailer's cost structure. Miyaoka and Hausman (2008), as well as Yue and Raghunathan (2007), show that under such a distortion better demand information could actually decrease a channel's expected profit. A number of papers study contracts that can eliminate the distortion, including the work on return policies by Pasternack (1985) and the study on quantity flexibility contract by Tsay (1999). Quite often channel inefficiency is due to information asymmetry among channel members. The remedy is to align the members' incentives to induce credible information sharing. Most studies in this stream focus on constructing incentive-compatible schemes through the principal-agent framework. Examples are study on asymmetric information about the retailer's cost structure (e.g., Corbett and Tang, 1999) and studies on asymmetric information on the demand level for the manufacturer's product (e.g., Chu, 1992; Cachon and Lariviere, 2001; Özer and Wei, 2006). By modeling demand uncertainty, we also examine the manufacturer's incentive to share his private demand information explicitly. Rather than designing contracts to eliminate information asymmetry, we focus on evaluating the performance of widely discussed contract forms when the manufacturer privately observes updated demand information.

Next we clarify the boundaries of our research by discussing what we do not study. This paper focuses on a supply chain setting in which the manufacturer offers the contract (as in Chu, 1992). Other supply chain scenarios are also possible. For example, the downstream firm may have better demand information, such as in the supplier–manufacturer context studied in Cachon and Lariviere

[3] Tirole (1988) provides several examples of incomplete contracts.

(2001) and Özer and Wei (2006). We refer readers who are interested in other contexts to their paper and references therein. This paper also does not aim to investigate complex signaling or screening mechanisms through which the new demand or cost information could be credibly shared (as in Corbett and Tang, 1999; Ha, 2001; Özer and Wei, 2006). Instead, the present paper's focus is merely on understanding whether a simple contract, designed without anticipating a demand information update, can continue to induce firms to credibly share this demand information update. Note that if such a contract is available, then there is no reason to design a complex contract to screen this information because the manufacturer will voluntarily share this information. Finally, we assume that the contract is signed long before the actual sales season. In particular at a time when both firms have common demand information. We note that there are various other plausible scenarios that one can investigate – hence supply chain contracting literature has grown tremendously over the last decade. We welcome other researchers contribution to extend this work and study other settings.

The rest of the paper is organized as follows. In Section 3, we formulate our model and establish a benchmark based on the centralized channel. In Section 4, we address channel incentives for information sharing and channel performance. In Section 5, we conclude the chapter.

3. Centralized channel: the benchmark

The new product's selling season is shorter than its production leadtime, so the retailer has one ordering opportunity. In other words, the manufacturer is selling to a retailer who operates as a newsvendor. Several high technology products, such as high definition televisions, and fashion apparel industry face similar dynamics. A toy manufacturer often decides how many items to manufacture in Asia and ship to North American retailers who sell during the Christmas season. Due to possibility of obsolescence or the nature of the business, the retailer does not have the ability to store inventory from one selling season to the next. Furthermore, the single selling season is not long enough to place a second order; that is, there is only one opportunity to stock the new product. In the computing industry, some retailers procure products in a single order for the entire life-cycle of a product. This process is referred to as "life-time-buy". We refer the reader to Kaya and Özer (forthcoming) for various other scenarios in which a newsvendor setting could be applicable.

After signing the contract and before introducing the product to the market, the manufacturer may update the product's demand information, which reduces demand uncertainty. For example, the manufacturer may obtain an unanticipated information regarding the new product's life cycle. This information impacts demand for the product. We provide an example to illustrate how this new information can affect demand. Let T denote the random life-cycle for the product. The following function is the simplest possible example of how the life-cycle can affect the demand for the product. $D = g(T) + \epsilon$, where $g(\cdot)$ is a nondecreasing function and ϵ is a zero mean random error term independent of T. This inverse relation between time and demand is intuitive and it is also well established (see, for example Billington et al., 1998; Erhun et al., 2007). The demand variance is given by $Var(D) = Var(g(T)) + Var(\epsilon)$, where $Var(g(T))$ is due to the new product's life-cycle uncertainty and $Var(\epsilon)$ is due to the inherent market uncertainty. Observing the new product's production readiness processes may provide information to reduce uncertainty in the product's life-cycle. This information may reduce the demand uncertainty for the product. Yet, this information often is not available to the retailer if the manufacturer does not share it.

We model the reduction in demand uncertainty by the *convex ordering* relationship (Müller and Stoyan, 2002).

Definition 1. Let X and Y be random variables with finite means. We say that X is larger than Y in convex order $X \geqslant_{cx} Y$, if $E[h(X)] \geqslant E[h(Y)]$ for all convex functions $h(\cdot)$.

Let D_1 and D_2 be random variables that represent the demand distribution respectively before and after an information update. If $D_1 \geqslant_{cx} D_2$, then we have (1) $E[D_1] = E[D_2]$ and (2) $Var[D_1] \geqslant Var[D_2]$. These two results are due to Theorem 1.5.3 in Müller and Stoyan (2002). Note that $T_1 \geqslant_{cx} T_2$, where T_i denotes the length of the new product's life-cycle before and after information update, implies $D_1 \geqslant_{cx} D_2$. When $D_1 \geqslant_{cx} D_2$, D_2 provides a more accurate prediction for the product's demand due to its smaller variance. Let $f_i(x)$ and $F_i(x)$ denote the probability density and cumulative distribution functions for demand D_i, $i = 1,2$. We assume that these distributions are continuous, invertible, and strictly increasing.

The product's unit retail price is p, and its unit production cost is c. Each unsold product at the end of the selling season has a salvage value c_s. We assume that $c > c_s$ to avoid the unrealistic scenario in which the channel makes unlimited profits. We also assume that $p > c$ to ensure the production is profitable. Let $E\Pi_s^i(Q)$ denote the expected channel profit when the channel's production quantity is Q and demand is D_i, $i = 1,2$. We have

$$E\Pi_s^i(Q) \equiv -cQ + \int_0^Q (c_s(Q-x) + px) f_i(x)dx + \int_Q^\infty pQ f_i(x)dx = (p-c)Q - (p-c_s)I_i(Q). \quad (1)$$

Here $I_i(Q) \equiv \int_0^Q F_i(x)dx$ is the expected leftover inventory when the production quantity is Q and the demand distribution is D_i. Under demand D_i, the optimal production quantity and the optimal expected profit for the centralized channel are

$$Q_i^I \equiv F_i^{-1}\left(\frac{p-c}{p-c_s}\right) \quad \text{and} \quad (2)$$

$$E\Pi_s^i\left(Q_i^I\right) \equiv (p-c)Q_i^I - (p-c_s)I_i\left(Q_i^I\right) \quad \text{for } i = 1,2. \quad (3)$$

We use $F_i\left(Q_i^I\right) = \frac{p-c}{p-c_s}$ to denote the channel's optimal service level under demand distribution D_i. Note that $F_i\left(Q_i^I\right)$ represents the probability of satisfying all demand during the selling season when the production quantity is Q_i^I, a term that is commonly referred as Type I service level (Nahmias, 2001). Given our assumptions regarding the cost parameters, the channel's service level is strictly between zero and one.

Lemma 1. *If $D_1 \geqslant_{cx} D_2$, then $E\Pi_s^2(Q_2^I) \geqslant E\Pi_s^1(Q_1^I)$.*

Lemma 1 shows that the centralized channel always benefits from improved demand information. Note that $E\Pi_s^2\left(Q_2^I\right) - E\Pi_s^1\left(Q_1^I\right)$ gives the value of the improved information. The convex ordering of D_1 and D_2, however, does not imply any ordering between the optimal production quantities. In fact, Gerchak and Mossman (1992) show that, for some demand distributions, a reduction in demand uncertainty might increase the optimal inventory level. Next, we obtain additional insights into the production quantity by using the *cut criterion* concept introduced by Karlin and Novikoff (1963).

Definition 2. Let X and Y be two random variables with cumulative distributions $F_X(\cdot)$ and $F_Y(\cdot)$, respectively. We say that X and Y satisfy the cut criterion at q' if there exists $q' < \infty$ such that $F_X(q) \geqslant F_Y(q)\ \forall q < q'$ and $F_X(q) \leqslant F_Y(q)\ \forall q \geqslant q'$.

The above definition essentially states that two random variables satisfy the *cut criterion* if their cumulative distribution functions cross exactly once (or equivalently if their density function cross exactly twice). Cut criterion is not a restrictive condition. Several pairs of random variables can satisfy this condition. For example, two normally distributed random variables with the same mean satisfy the *cut criterion* at q' equal to the mean. In fact, any random variable with unimodal probability distribution satisfy the cut criterion. Note also that in the above definition X and Y do not have to be from the same family of distributions. However, the *cut criterion* is stronger than convex ordering; that is, $D_1 \geqslant_{cx} D_2$ does not guarantee the satisfaction of the *cut criterion*.

Lemma 2. *If D_1 and D_2 satisfy the cut criterion at $q' < \infty$, then $Q_1^I \geqslant Q_2^I$ for $F_1(q') \leqslant \frac{p-c}{p-c_s}$ and $Q_1^I \leqslant Q_2^I$ otherwise.*

The above result shows that the ordering between Q_1^I and Q_2^I depends on the channel's optimal service level and the crossing location of $F_1(\cdot)$ and $F_2(\cdot)$. For example, when both D_1 and D_2 are normally distributed with the same mean, we have $F_1(q') = 0.5$. Thus, if the optimal service level is below 50%, the channel's optimal production quantity increases when demand uncertainty decreases.

4. Information sharing and channel performance

In the decentralized channel, the retailer faces the customer demand, while the manufacturer manages the production. Both firms maximize their own profits from the product. Production cost c is incurred at the manufacturer, and the unit retail price p is collected at the retailer. At the end of the selling season, each unsold product is salvaged at value c_s. The payment between the manufacturer and the retailer depends on an agreed upon contract, and the retailer has only one ordering opportunity.

Both firms have the demand information D_1 and agree to honor a supply contract prior to the sales season. When both firms agree on the contract terms, they do not anticipate possibility of an information update. Recall that the goal is to investigate whether some widely used contracts that are shown to be equivalent are also equally robust under a set of unpredictable events that affect demand information. To investigate this question, we introduce a random "perturbation" to the system after the contract design problem is solved. To do so, suppose that the manufacturer observes demand signals and updates his demand information to D_2. Note that this new perturbation is not part of the sequence of events that the manufacturer or the retailer had anticipated. Hence, this "stage" in the sequence does not exist when the manufacturer offers the contract. The question we investigate is whether the agreed upon contract is robust enough to keep incentives aligned such that the manufacturer would reveal this private information. This would be the case if he is not worse off under the agreed upon contract or if he is mandated by the contract to do so. The retailer updates her demand information to D_2 if the manufacturer shares this unanticipated private information. The manufacturer delivers the amount ordered by the retailer prior to the selling season.

From Lemma 1, we know that the centralized channel benefits from updating the demand information from D_1 to D_2. We are interested in determining whether the decentralized channel can also benefit from the improved demand information. To do so, we investigate the manufacturer's incentive to share his private information and the impact of mandatory information disclosure under three widely used contract forms.

4.1. Price-only contracts

A price-only contract specifies only the wholesale price $w > c$ that the retailer pays for each product. Even when no information asymmetry exists, a price-only contract cannot achieve channel coordination unless the manufacturer sells the product at its production cost. In practice, however, price-only contracts are common because of their simplicity.

Given a wholesale price w, the retailer orders to maximize her profit based on her demand information. The retailer's optimal order quantity, her expected profit, and the manufacturer's profit are given by

$$Q_i^* = F_i^{-1}\left(\frac{p-w}{p-c_s}\right), \tag{4}$$

$$E\Pi_r(Q_i^*) = (p-w)Q_i^* - (p-c_s)I_2(Q_i^*) \quad \text{and} \tag{5}$$

$$\Pi_m(Q_i^*) = (w-c)Q_i^* \quad \text{for } i \in \{1,2\}. \tag{6}$$

Note that the manufacturer's profit depends indirectly on the retailer's demand information through her order quantity. The retailer orders Q_2^* units only when the manufacturer shares his improved demand information D_2. Although the retailer's optimal order quantity with information sharing is different from that without information sharing, all channel members' true expected profits depend on D_2.

The retailer's problem is the same as the problem for the centralized channel except for the marginal profit. As shown by Lemma 1, the retailer always benefits from learning the manufacturer's improved demand information D_2. The manufacturer, however, will voluntarily share this information only if his payoff from doing so is nonnegative.

Given a wholesale price w, the manufacturer's profit increases with the retailer's order quantity. Thus, the manufacturer benefits from sharing D_2 if $Q_2^* \geqslant Q_1^*$. Let $E\Pi_s(Q_i^*) \equiv \Pi_m(Q_i^*) + E\Pi_r(Q_i^*)$ represent the expected total channel profit when the retailer's order quantity is Q_i^*. Note that $E\Pi_s(Q_1^*)$ and $E\Pi_s(Q_2^*)$ represent, respectively, the expected total channel profit when the retailer has and does not have information D_2. The following proposition reveals issues in information sharing under a price-only contract.

Proposition 1. *Assume that D_1 and D_2 satisfy the cut criterion at $q' < \infty$.*

(i) *For $F_1(q') \geqslant \frac{p-w}{p-c_s}$, we have $\Pi_m(Q_2^*) \geqslant \Pi_m(Q_1^*)$; otherwise, $\Pi_m(Q_2^*) < \Pi_m(Q_1^*)$.*
(ii) *For $F_1(q') \geqslant \frac{p-w}{p-c_s}$, we have $E\Pi_s(Q_2^*) \geqslant E\Pi_s(Q_1^*)$.*
(iii) *For $F_1(q') < \frac{p-w}{p-c_s}$ and $F_2(Q_1^*) \leqslant \frac{p-c}{p-c_s}$, we have $E\Pi_s(Q_2^*) \leqslant E\Pi_s(Q_1^*)$.*

Part (i) of Proposition 1 shows that the manufacturer receives a positive payoff from sharing his improved demand information only when $F_1(q') \geqslant \frac{p-w}{p-c_s}$. Otherwise, by keeping this information private the manufacturer gains additional profit. Recall that $\frac{p-w}{p-c_s}$ is the optimal service level for the retailer as well as for the channel. From the definition of the *cut criterion*, we know that probability distributions of D_1 and D_2 determine q' and $F_1(q')$. If we use $F_1(q')$ as a threshold, then the result states that information sharing is achievable only when the channel's service level $\frac{p-w}{p-c_s}$ is lower than the threshold $F_1(q')$. As a result, there exists a conflict between the channel's service level and the manufacturer's incentive for information sharing. For example, when D_1 and D_2 are both symmetric and unimodal, one can verify that $F_1(q') = 0.5$. In this case, the manufacturer receives a positive payoff from sharing the improved demand information only when the channel's optimal service level is below 50%.

Parts (ii) and (iii) of Proposition 1 reveal that having the manufacturer disclose his information lowers total channel profit when the manufacturer does not benefit from doing so. This result is counter-intuitive at first, since one expects higher channel profit from information sharing. Detailed analysis reveals that the underlying causes are the double marginalization effect and the properties of $F_i(\cdot)$. When $F_1(q') < \frac{p-w}{p-c_s}$, $w > c$ implies $F_1(q') < \frac{p-c}{p-c_s}$. From Eq. (2), we have $Q_1^I \geqslant Q_2^I$ and $Q_1^* \geqslant Q_2^*$; that is, the optimal order quantity for both the centralized channel and the retailer are smaller under the improved demand information. Because of the double marginalization effect, we have $Q_1^I > Q_1^*$; that is, the optimal order quantity for the retailer is smaller than that for the centralized channel. When the impact from double marginalization is larger than that from the improved demand information, we could observe $Q_1^I \geqslant Q_2^I \geqslant Q_1^* \geqslant Q_2^*$. Recall that Q_2^I is the optimal order quantity for the centralized channel under the improved demand information. Information sharing shifts the retailer's optimal order quantity from Q_1^* to Q_2^*, a quantity that is even lower than Q_2^I. As a result, we have $E\Pi_s(Q_2^I) \geqslant E\Pi_s(Q_1^*) \geqslant E\Pi_s(Q_2^*)$; that is, information sharing reduces the expected total channel profit. In summary, under a price-only contract, the retailer always benefits from having improved information D_2, but her benefit may come at a cost for the manufacturer.

4.2. Quantity flexibility contracts

Under a quantity flexibility contract, the manufacturer and the retailer agree on the wholesale price w and a return fraction limit $r \in (0,1)$. If the retailer's order quantity is Q, then she can return up to rQ units to the manufacturer for a full refund. Pasternack (1985) has shown that the quantity flexibility contract can coordinate the channel and allow an arbitrary division of total channel profits between channel members. Recall that both the manufacturer and the retailer can salvage each unsold product at a unit price of c_s. Since $c_s < w$, the retailer uses her return option before disposing of leftover inventories.

Under a quantity flexibility contract, the retailer chooses her optimal order quantity by maximizing the following expected profit function:

$$\begin{aligned}E\Pi_r^i(Q) &= -wQ + \int_0^{(1-r)Q} (px + wQr + c_s((1-r)Q - x))f_i(x)dx \\ &\quad + \int_{(1-r)Q}^{Q} (px + w(Q-x))f_i(x)dx + pQ\overline{F_i}(Q) \\ &= (p-w)\int_0^Q xf_i(x)dx + (p-w)Q\overline{F_i}(Q) \\ &\quad - (w-c_s)\int_0^{(1-r)Q} F_i(x)dx,\end{aligned}$$

where $\overline{F_i}(\cdot) \equiv 1 - F_i(\cdot)$. The retailer's demand information D_i depends on whether the manufacturer discloses his private demand information. The expected profit function is concave and the retailer's optimal order quantity Q_i^* must satisfy the following condition:

$$\frac{F_i\big((1-r)Q_i^*\big)}{1 - F_i(Q_i^*)} = \frac{(p-w)}{(w-c_s)(1-r)} \quad \text{for } i \in \{1,2\}. \tag{7}$$

With the retailer's order quantity Q_i^*, the retailer's and the manufacturer's expected profits are, respectively,

$$\begin{aligned}E\Pi_r(Q_i^*) &= (p-w)\int_0^{Q_i^*} xf_2(x)dx + (p-w)Q_i^*\overline{F_2}(Q_i^*) \\ &\quad - (w-c_s)\int_0^{(1-r)Q_i^*} F_2(x)dx \quad \text{and}\end{aligned}$$

$$\begin{aligned}E\Pi_m(Q_i^*) &= (w-c)Q_i^* - (w-c_s)\int_0^{(1-r)Q_i^*} rQ_i^* f_2(x)dx \\ &\quad - (w-c_s)\int_{(1-r)Q_i^*}^{Q_i^*} (Q_i^* - x)f_2(x)dx.\end{aligned}$$

We focus on investigating a quantity flexibility contract that achieves channel coordination when the channel members sign the contract. Demand information is D_1, and the retailer's optimal order quantity Q_1^* is equal to the channel's optimal order quantity Q_1^I when $F_1(Q_1^*) = F_1\big(Q_1^I\big)$. From Eq. (2) that $F_1\big(Q_1^I\big) = \frac{p-c}{p-c_s}$. By substituting Q_1^I in Eq. (7) and solving for w, we obtain the following condition:

$$(w,r) = \left(\frac{(c-c_s)p + c_s(1-r)(p-c_s)F_1\big((1-r)Q_1^I\big)}{(c-c_s) + (1-r)(p-c_s)F_1\big((1-r)Q_1^I\big)}, r\right). \tag{8}$$

Any pair (w,r) that satisfies the above condition coordinates the channel before the demand information update.

If the manufacturer discloses his improved demand information, then the retailer updates her demand information to D_2 and orders Q_2^*. When the retailer's on-hand demand information is D_i, Eq. (7) implies that the retailer's optimal service level is $F_i(Q_i^*) = 1 - \frac{(w-c_s)(1-r)F_i\left((1-r)Q_i^*\right)}{(p-w)}$. After the retailer updates her information, we have $F_2(Q_2^*) \neq F_1(Q_1^*) = F_1\big(Q_1^I\big)$; that is, the channel is no longer coordinated. The following lemma states that the optimal service level in a *decentralized channel* could be higher than that in a *centralized channel*.

Lemma 3. *Assume that D_1 and D_2 satisfy the cut criterion at q'. If $q' \in ((1-r)Q_1^*, Q_1^*]$, then $F_2(Q_2^*) \geqslant F_1(Q_1^*)$.*

The above result indicates that under a quantity flexibility contract, the channel loses its first-best performance. One might hope that the quantity flexibility contract can at least induce the manufacturer to share his improved demand information. The following result states that this is not always true. Recall that $E\Pi_s(Q_i^*)$ represents the expected total channel profit when the retailer's order quantity is Q_i^*. Note that Q_2^* satisfies Eq. (7) under demand distribution F_2, so Q_2^* depends on the value of the return ratio r. We use $Q_2^*(r)$ to emphasize this dependency.

Proposition 2. *Assume that D_1 and D_2 satisfy the cut criterion at q', and let $a = \sup\{q : F_1(q) = 0\}$. If $S(q) \equiv \frac{F_2(q)}{F_1(q)}$ is increasing in $q \in (a, q')$, $f_i(\cdot)$ is symmetric for $i \in \{1,2\}$, and $Q_1^* > E(D_1)$, then there exists a $\hat{r} \in (0,1)$ such that for any $r \in [\hat{r}, 1)$ we have*

(i) $Q_2^*(r) \geqslant Q_2^*(\hat{r}) = Q_1^*$,
(ii) $E\Pi_s(Q_1^*) \geqslant E\Pi_s(Q_2^*(r))$,
(iii) $E\Pi_m(Q_1^*) \geqslant E\Pi_m(Q_2^*(r))$.

Proposition 2 states that there exists a return ratio $\hat{r}$ such that the retailer will order the same quantity under both demand distributions D_1 and D_2. If the return ratio r is larger than $\hat{r}$, part (i) shows that the retailer orders more under demand distribution D_2. However, part (iii) states that the manufacturer receives negative payoff from disclosing D_2. Thus, if the return ratio of a quantity flexibility contract is above the threshold $\hat{r}$, the self-interested manufacturer does not have an incentive to share his information. Note that both normal and uniform distributions satisfy the conditions stated in Proposition 2.

Part (ii) states that mandating the manufacturer to disclose his improved demand information D_2 reduces total channel profit when the return ratio is above the threshold $\hat{r}$. This appears counter-intuitive at first, because one usually expects better channel performance under improved demand information. Careful analysis, however, reveals that this result is due to the distortion in the retailer's cost structure and the behavior of $F_i(\cdot)$. By the symmetry of $f_i(\cdot)$, we have $q' = E(D_1)$. Since $Q_1^* = Q_1^I > E(D_1)$, we have $F_1\big(Q_1^I\big) > F_1(q')$. From Lemma 2 we have $Q_1^I \geqslant Q_2^I$. That is, the centralized channel orders less after improving the demand information. Lemma 3 indicates that when the return ratio r is high, updating demand distribution to D_2 results in $F_2(Q_2^*) \geqslant F_2\left(Q_2^I\right)$, which equivalently means $Q_2^* \geqslant Q_2^I$. That is, information sharing distorts the retailer's cost structure, which offers her the opportunity to take advantage of the return limit to achieve a service level higher than the channel's optimum. When cost distortion results in a large increase from Q_2^I to Q_2^* and updating demand information generates a small reduction from Q_1^I to Q_2^I, we could have $Q_2^* \geqslant Q_1^I = Q_1^* \geqslant Q_2^I$. Recall that Q_2^I is the optimal order quantity for the centralized channel under the improved demand information D_2. Information sharing shifts the retailer's optimal quantity from Q_1^* to Q_2^*, a quantity that is further away from Q_2^I. As a result, we have $E\Pi_s\left(Q_2^I\right) \geqslant E\Pi_s(Q_1^*) \geqslant E\Pi_s(Q_2^*)$; that is, information sharing reduces the expected total channel profit. Note that the magnitude of cost distortion, as well as the difference between Q_2^* and Q_2^I, depends on both the return ratio r and the behavior of $F_i(\cdot)$; whereas, the difference between Q_1^I and Q_2^I depends only on the behavior of $F_i(\cdot)$.

We demonstrate results from Theorem 3 further through an example. Fig. 1 plots the manufacturer's payoff from information sharing with respect to the return ratio r. Reduction in demand uncertainty is the largest for Curve C and the smallest for Curve A. For all three cases, the manufacturer's payoff from sharing information is positive when $r \in (0, \hat{r})$ and negative when $r \in (\hat{r}, 1)$. Curve C has the largest positive payoff when $r \in (0, \hat{r})$ and the largest negative payoff when $r \in (\hat{r}, 1)$. This implies that a large reduction in demand uncertainty could give the manufacturer either a strong incentive or a strong dis-incentive in information sharing. Therefore, setting a proper return ratio r is very important for a quantity flexibility contract to induce information sharing.

Fig. 2 plots the total channel profit with respect to the return ratio r. Line A and Line B represent channel profits under centralized control with demand D_1 and D_2, respectively. Curve C and Curve D illustrate the total channel profit under quantity flexible contracts that satisfy the condition in Eq. (13). In Curve C, the retailer always has access to new demand D_2, while in Curve D, she has access to D_2 only when the manufacturer has an incentive to share his new demand information D_2. For the centralized channel, profit is always higher with smaller demand variance. Both Curve C and Curve D are below Line B, which shows that the performance of quantity flexible contracts is always worse than the first-best solution. When the return ratio r is larger than $\hat{r}$, Curve C lies below Curve D, which illustrates that sharing information could worsen channel performance. When the return ratio r is very large, Curve C even drops below Line A. This emphasizes that, in a decentralized channel, more information could be harmful if one does not design the channel contract carefully. In other words, if the contract is not robust, the unanticipated signals affecting manufacturer's demand information could be quite harmful. In summary, quantity flexibility contracts with high return rates are not robust contracts.

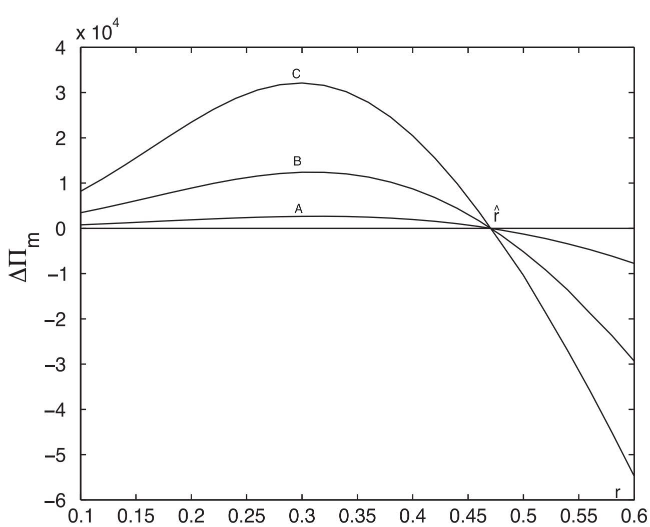

Fig. 1. An example of manufacturer's payoff from information sharing under quantity flexible contracts.

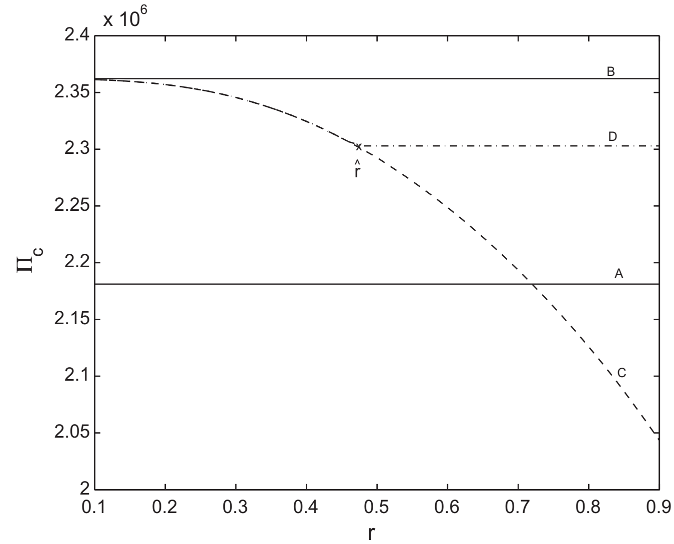

Fig. 2. An example of total channel profit with demand forecast update.

Recall the similar result in Proposition 1 for a price-only contract. The difference between these results lies in how the retailer's order quantity changes when the manufacturer discloses his improved demand information. Under a quantity flexibility contract, the channel could be worse off, since we could have $Q_2^* \geqslant Q_1^I = Q_1^* \geqslant Q_2^I$. That is, given the new information, the retailer's optimal order quantity is larger than that of the centralized channel. Thus, one would expect larger excess inventory. On the other hand, under a price-only contract, the channel could be worse off, since we could have $Q_1^I \geqslant Q_2^I \geqslant Q_1^* \geqslant Q_2^*$. That is, given the new information, the retailer's optimal order quantity is smaller than that of the centralized channel. Thus, one would expect a greater loss of sales.

4.3. Buyback contracts

In a buyback contract, the channel members set the wholesale price w and the return credit c_r so that the manufacturer agrees to pay the retailer for each unsold product. We assume that $w > c_r \geqslant c_s$. When the retailer's demand information is D_i for $i = 1,2$, the retailer's optimal order quantity, her expected profit, and the manufacturer's expected profit are

$$Q_i^* = F_i^{-1}\left(\frac{p-w}{p-c_r}\right), \tag{9}$$

$$E\Pi_r(Q_i^*) = (p-w)Q_i^* - (p-c_r)I_2(Q_i^*), \quad \text{and} \tag{10}$$

$$E\Pi_m(Q_i^*) = (w-c)Q_i^* - (c_r-c_s)I_2(Q_i^*), \tag{11}$$

respectively. As under a quantity flexibility contract, the retailer bases her order on either D_1 or D_2, depending on whether the manufacturer discloses his private information.

We also focus on investigating a buyback contract that achieves channel coordination and eliminates the double marginalization effect when the contract was first signed. Recall that the firms sign the buyback contract when the demand information is D_1. The retailer's optimal order quantity also maximizes the channel profit if $F_1^{-1}\left(\frac{p-w}{p-c_r}\right) = F_1^{-1}\left(\frac{p-c}{p-c_s}\right)$, which is equivalent to

$$\frac{p-w}{p-c_r} = \frac{p-c}{p-c_s}. \tag{12}$$

Correspondingly, $E\Pi_r(Q_1^*) = \left(\frac{p-c_r}{p-c_s}\right)E\Pi_s(Q_1^*)$, which states that the division of channel profit is independent of the demand information D_1.

Proposition 3. *For a buyback contract that satisfies Eq. (12), we have (i) $E\Pi_m(Q_2^*) \geqslant E\Pi_m(Q_1^*)$ and (ii) $E\Pi_s(Q_2^*) \geqslant E\Pi_s(Q_1^*)$.*

Once w and c_r are chosen to coordinate the channel, both the manufacturer and the retailer receive a fixed portion of the total channel profit. The division of the profit is independent of the demand information. Furthermore, the manufacturer knows that the retailer's optimal order quantity under D_2 maximizes the total channel profit because updating the demand information from D_1 to D_2 does not distort the retailer's cost structure. When demand uncertainty decreases, both the manufacturer's profit and the retailer's profit increase because the total channel profit increases. Hence, under the buyback contract the manufacturer has an incentive to share his improved demand information and the channel's best performance is preserved. We find that buyback contracts perform well because the division of channel profits between channel members is independent of the demand distribution.

Recall that $E\Pi_s^i(Q)$ denotes the expected channel profit when the new product's demand information is D_i. Similarly, let $E\Pi_m^i(Q)$ and $E\Pi_r^i(Q)$, respectively, to represent the manufacturer's and the retailer's expected profit when the new product's demand information is D_i. For the centralized channel, the benefit from improving the new product's demand information is $\Delta E\Pi_s \equiv E\Pi_s^2(Q_2^I) - E\Pi_s^1(Q_1^I)$. From Proposition 3 we know that the manufacturer has the incentive to share D_2 with the retailer. Subsequently, the retailer would order Q_2^* instead of Q_1^*. Thus, the manufacturer's and the retailer's benefits from sharing this information are $\Delta E\Pi_m \equiv E\Pi_m^2(Q_2^*) - E\Pi_m^1(Q_1^*)$ and $\Delta E\Pi_r \equiv E\Pi_r^2(Q_2^*) - E\Pi_r^1(Q_1^*)$, respectively. We have $\Delta E\Pi_s = \Delta E\Pi_m + \Delta E\Pi_r$, because $Q_i^* = Q_i^I$ for a buyback contract that satisfy condition as specified in Eq. (12). The following proposition characterizes the manufacturer's and retailer's benefits from sharing information.

Proposition 4. *$\Delta E\Pi_m$ is increasing (and $\Delta E\Pi_r$ is decreasing) in c_r. In addition, $\lim_{(w-c_r)\to 0}\Delta E\Pi_m = \Delta E\Pi_s$.*

5. Conclusion

This paper uses the concept of convex ordering to model information updates that reduce a new product's demand uncertainty. In a centralized channel, we show that reducing demand uncertainty improves the channel's expected total profit. In a decentralized channel, as the developer of the new product, the manufacturer may observe improved demand information after signing a supply contract with the retailer. We evaluate the manufacturer's incentive to share his improved demand information as well as the impact of mandatory information disclosure. Among the contract forms addressed, we determine that the price-only contract achieves information sharing only when the channel's optimal service level is low, while the quantity flexibility contract achieves information sharing only when the return ratio is low. The buyback contract, however, always achieves information sharing and preserves channel performance. We also contribute to the existing literature by showing that for the quantity flexibility contract and the price-only contract, mandating the manufacturer to disclose his private information eliminates information asymmetry but may result in lower channel profit. Close examination reveals that the inefficiency is from the distortion in the retailer's cost structure and the behavior of the demand distribution.

Previous studies have shown that both buyback contracts and quantity flexibility contracts can coordinate a channel. In addition, both contract forms allow the manufacturer and the retailer to divide the total channel profit arbitrarily. Hence, it has been argued that these contracts are equivalent. However, our study shows that these contracts performances are significantly different when unanticipated information evolution generates information asymmetry at the manufacturer's side. On one hand, a buyback contract that coordinates the channel before information updates can always achieve information sharing and preserve the first-best performance. On the other hand, a similar quantity flexibility contract loses the first-best performance even when information sharing is achievable. This difference in channel performance occurs because changes in demand uncertainty under the quantity flexibility contract introduce new distortion into the retailer's cost structure. In summary, in an environment where the manufacturer has a better opportunity in reducing demand uncertainty for a new product, the buyback contract stands out as the most effective solution in preserving channel performance under frequent information updates. Hence, we conclude that buyback contracts are robust under unanticipated demand information updates. This may be one of the reason why buyback contracts are more prevalent in practice.

There are various opportunities for future research. One immediate research question is to design contracts that are incentive compatible with respect to demand information updates although the resulting contract will surely be not as simple as those discussed in this paper. It would also be interesting to study the performance of contracts in long-term relationships in which multiple ordering and demand information updates are possible. In addition, we have shown that price-only contracts are not robust under information updates. Why then this contract is still used widely? Recent research has started to investigate these issues (Özer et al., 2009). Yet, more research is needed to shed light on what makes a contract robust and amenable for implementation.

Appendix A

Proof of Lemma 1. The proof is done by showing $E\Pi_s^2\left(Q_2^I\right) \geqslant E\Pi_s^2\left(Q_1^I\right) \geqslant E\Pi_s^1\left(Q_1^I\right)$. The first inequality is from the definition of Q_2^I. Note that given a production quantity Q and demand realization d, the channel profit, which is given by $(p-c)Q-(p-c_s)(Q-d)^+$, is a concave function in d. From the definition of convex ordering, $D_1 \geqslant_{cx} D_2$ indicates $E(h(D_1)) \geqslant E(h(D_2))$ for all convex functions $h(\cdot)$. The second inequality follows from letting $h(d) = -\left[(p-c)Q_1^I - (p-c_s)\left(Q_1^I - d\right)^+\right]$. □

Proof of Lemma 2. First we show that if $F_1(q') \leqslant \frac{p-c}{p-c_s}$, then $Q_1^I \geqslant Q_2^I$. Assume for a contradiction that $Q_1^I < Q_2^I$. Since $F_2(q)$ is increasing in q, we have $F_2\left(Q_1^I\right) < F_2\left(Q_2^I\right)$. Recall that by definition of Q_i^I we have $F_1\left(Q_1^I\right) = F_2\left(Q_2^I\right) = \frac{p-c}{p-c_s}$. This indicates $F_2\left(Q_1^I\right) < F_1\left(Q_1^I\right)$. From the definition of *cut criterion*, we have $q' > Q_1^I$, or equivalently, $F_1(q') > F_1\left(Q_1^I\right)$. This contradicts the initial condition $F_1(q') \leqslant \frac{p-c}{p-c_s}$. Thus, we must have $Q_1^I \geqslant Q_2^I$. A similar contradiction argument proves that $Q_1^I \leqslant Q_2^I$ for $F_1(q') \geqslant \frac{p-c}{p-c_s}$. □

Proof of Proposition 1. Notice that from Lemma 2 we have $Q_1^* \geqslant Q_2^*$ for $F_1(q') \leqslant \frac{p-w}{p-c_s}$ and $Q_1^* \leqslant Q_2^*$ otherwise. Part (i) follows directly from this result since the manufacturer's profit function equation (6) is increasing in the retailer's order quantity.

To prove part (ii) note first that the retailer's profit is maximized at Q_2^* when the demand is D_2, that is $E\Pi_r(Q_2^*) \geqslant E\Pi_r(Q_1^*)$. Together with part (i), this result implies that $\Pi_m(Q_2^*) + E\Pi_r(Q_2^*) = E\Pi_s(Q_2^*) \geqslant E\Pi_s(Q_1^*)$ when $F_1(q') \geqslant \frac{p-w}{p-c_s}$, which concludes the proof of part (ii).

When $F_1(q') < \frac{p-w}{p-c_s}$, we have

$$\begin{aligned}E\Pi_s(Q_2^*) - E\Pi_s(Q_1^*) &= (p-c)(Q_2^* - Q_1^*) \\ &\quad - (p-c_s)\left(\int_0^{Q_2^*} F_2(x)dx - \int_0^{Q_1^*} F_2(x)dx\right) \\ &= (p-c_s)\left(\int_{Q_2^*}^{Q_1^*} F_2(x)dx - \frac{p-c}{p-c_s}(Q_1^* - Q_2^*)\right) \\ &\leqslant (p-c_s)\left(F_2(Q_1^*)(Q_1^* - Q_2^*) - \frac{p-c}{p-c_s}(Q_1^* - Q_2^*)\right),\end{aligned}$$

where the inequality is because $Q_1^* \geqslant Q_2^*$ when $F_1(q') < \frac{p-w}{p-c_s}$ and $F_2(\cdot)$ is an increasing function. If $F_2(Q_1^*) \leqslant \frac{p-c}{p-c_s}$, then $E\Pi_s(Q_2^*) - E\Pi_s(Q_1^*) \leqslant 0$, which implies part (iii). □

Proof of Lemma 3. When $Q_2^* \geqslant Q_1^* \geqslant q'$, we have $F_2(Q_2^*) \geqslant F_1(Q_2^*) \geqslant F_1(Q_1^*)$, where the first inequality is from D_1 and D_2 satisfies the *cut criterion* at q'. When $Q_2^* < Q_1^*$, we have $q' > (1-r)Q_1^* > (1-r)Q_2^*$ and consequently $F_1((1-r)Q_1^*) > F_1((1-r)Q_2^*) > F_2((1-r)Q_2^*)$ by the property of the *cut criterion*. $F_2(Q_2^*) > F_1(Q_1^*)$ follows directly from $F_i(Q_i^*) = 1 - \frac{(w-c_s)(1-r)F_i((1-r)Q_i^*)}{(p-w)}$, which concludes the proof. □

Proof of Proposition 2. Let $\hat{r}$ be the return ratio that satisfies $\frac{p-w}{(w-c_s)(1-\hat{r})} = 1$. Note that Q_1^* and $Q_2^*(\hat{r})$ should satisfy the first order condition

$$\frac{F_1((1-\hat{r})Q_1^*)}{1-F_1(Q_1^*)} = \frac{F_2((1-\hat{r})Q_2^*(\hat{r}))}{1-F_2(Q_2^*(\hat{r}))} = 1. \tag{13}$$

We have $F_1((1-\hat{r})Q_1^*) = 1 - F_1(Q_1^*) = F_1(2E(D_1) - Q_1^*)$. The first equality is from Eq. (13) and the second is from $f_1(\cdot)$ being symmetric. This indicates $Q_1^* = \frac{2E(D_1)}{2-\hat{r}}$. Similarly, we can verify that $Q_2^*(\hat{r}) = \frac{2E(D_2)}{2-\hat{r}}$, which leads us to $Q_2^*(\hat{r}) = Q_1^*$ because $E(D_1) = E(D_2)$ from convex ordering. Note that $\hat{r} = 2\left(1 - \frac{E(D_1)}{Q_1^*}\right)$. By our assumption that $E(D_1) < Q_1^*$ and D_1 is symmetric, we have $\frac{E(D_1)}{Q_1^*} \in (\frac{1}{2}, 1)$, which indicates $\hat{r} \in (0,1)$. This shows the existence of $\hat{r}$ as a feasible return ratio for which the retailer order quantity is the same before and after information update.

Because $E(D_1) = E(D_2)$ and both D_1 and D_2 are symmetric, we have $F_1(E(D_1)) = F_2(E(D_2)) = \frac{1}{2}$. Since D_1 and D_2 satisfy the *cut criterion* at q', we have $F_1(q') = F_2(q')$, which indicates $q' = E(D_1)$. For any $r \in [\hat{r}, 1)$,

$$(1-r)Q_2^*(\hat{r}) \leqslant (1-\hat{r})Q_2^*(\hat{r}) = (1-\hat{r})\frac{2E(D_1)}{2-\hat{r}} < E(D_1).$$

By our assumption that $\frac{F_2(q)}{F_1(q)}$ is increasing in (a, q'), where $a = \sup\{q : F_1(q) = 0\}$ and $\hat{r} \leqslant r$ we have

$$\frac{F_2((1-r)Q_2^*(\hat{r}))}{F_2((1-\hat{r})Q_2^*(\hat{r}))} \leqslant \frac{F_1((1-r)Q_2^*(\hat{r}))}{F_1((1-\hat{r})Q_2^*(\hat{r}))}. \tag{14}$$

From Eq. (13),

$$\frac{1}{1-F_2(Q_2^*(\hat{r}))} = \frac{F_1((1-\hat{r})Q_1^*)}{(1-F_1(Q_1^*))F_2((1-\hat{r})Q_2^*(\hat{r}))}.$$

Therefore,

$$\begin{aligned}\frac{F_2((1-r)Q_2^*(\hat{r}))}{1-F_2(Q_2^*(\hat{r}))} &= \frac{F_2((1-r)Q_2^*(\hat{r}))}{F_2((1-\hat{r})Q_2^*(\hat{r}))} \times \frac{F_1((1-\hat{r})Q_1^*)}{1-F_1(Q_1^*)} \\ &\leqslant \frac{F_1((1-r)Q_2^*(\hat{r}))}{F_1((1-\hat{r})Q_2^*(\hat{r}))} \times \frac{F_1((1-\hat{r})Q_1^*)}{1-F_1(Q_1^*)} \quad \text{due to Eq. (14)} \\ &= \frac{F_1((1-r)Q_1^*)}{1-F_1(Q_1^*)} \quad \text{because } Q_2^*(\hat{r}) = Q_1^* \\ &= \frac{F_2((1-r)Q_2^*(r))}{1-F_2(Q_2^*(r))} \quad \text{due to Eq. (7)}.\end{aligned}$$

It can be shown that $\partial\left(\frac{F_2((1-r)q)}{1-F_2(q)}\right)\Big/\partial q \geqslant 0$. Together with the above inequality, this implies that $Q_2^*(r) \geqslant Q_2^*(\hat{r})$ for any $r \in [\hat{r}, 1)$. Therefore, there exists an $\hat{r} \in (0,1)$ such that for all $r \in [\hat{r}, 1)$ we have $Q_2^*(r) \geqslant Q_2^*(\hat{r}) = Q_1^*$.

Based on the definition of $E\Pi_s(\cdot)$, for any $r \in [\hat{r}, 1)$ we have

$$\begin{aligned}E\Pi_s(Q_1^*) - E\Pi_s(Q_2^*(r)) &= (p-c)(Q_1^* - Q_2^*(r)) - (p-c_s)\int_{Q_2^*(r)}^{Q_1^*} F_2(x)dx \\ &\geqslant (p-c_s)(Q_2^*(r) - Q_1^*)F_2(Q_1^*) - (p-c)(Q_2^*(r) - Q_1^*) \\ &\geqslant (p-c_s)(Q_2^*(r) - Q_1^*)F_1(Q_1^*) - (p-c)(Q_2^*(r) - Q_1^*) \\ &= 0.\end{aligned}$$

The first inequality is from $Q_2^*(r) \geqslant Q_1^*$ for $r \in [\hat{r}, 1)$ and $F_2(\cdot)$ is an increasing function; the second inequality is because D_1 and D_2 satisfy the *cut criterion* at $q' = E(D_1)$ and $Q_1^* > E(D_1)$; the last equality is from $F_1(Q_1^*) = \frac{p-c}{p-c_s}$.

For any $r \in [\hat{r}, 1)$, we have $E\Pi_m(Q_1^*) \geqslant E\Pi_m(Q_2^*(r))$ comes directly from $E\Pi_s(Q_1^*) \geqslant E\Pi_s(Q_2^*(r))$ but $E\Pi_r(Q_1^*) \leqslant E\Pi_r(Q_2^*(r))$, since $Q_2^*(r)$ is the retailer's optimal order quantity under demand distribution D_2. □

Proof of Proposition 3. Let $\Delta \equiv E\Pi_m(Q_2^*) - E\Pi_m(Q_1^*)$, that is

$$\Delta = (w-c)(Q_2^* - Q_1^*) - (c_r - c_s)\left[\int_0^{Q_2^*} F_2(x)dx - \int_0^{Q_1^*} F_2(x)dx\right]. \tag{15}$$

Note that a coordinating buyback contract with (w, c_r) should satisfy Eq. (12). Hence, $\frac{\partial w}{\partial c_r} = \frac{p-c}{p-c_s}$, which is also equal to $F_2(Q_2^*)$ from the definition in (9). This gives us

$$\frac{\partial \Delta}{\partial c_r} = F_2(Q_2^*)(Q_2^* - Q_1^*) - \int_{Q_1^*}^{Q_2^*} F_2(x)dx \geqslant 0.$$

The inequality is because $\int_{Q_1^*}^{Q_2^*} F_2(x)dx \leqslant \int_{Q_1^*}^{Q_2^*} F_2(Q_2^*)dx = F_2(Q_2^*)(Q_2^* - Q_1^*)$ for $Q_2^* \geqslant Q_1^*$ and $\int_{Q_2^*}^{Q_1^*} F_2(x)dx > F_2(Q_2^*)(Q_1^* - Q_2^*)$ for $Q_2^* < Q_1^*$. Thus, Δ is increasing in c_r.

Note that c_r is also increasing in w. From Eq. (12), when $c_r = c_s$ we have $w = c$. Hence $\Delta = 0$. For any $w \geqslant c$, we have $c_r \geqslant c_s$ and since Δ is increasing in c_r we have $\Delta \geqslant 0$, which proves part (i) of the proposition.

Note that $E\Pi_s(Q_i^*) = E\Pi_m(Q_i^*) + E\Pi_r(Q_i^*)$. Part (ii) comes directly from $E\Pi_r(Q_2^*) \geqslant E\Pi_r(Q_1^*)$, since Q_2^* is the retailer's optimum order quantity under demand distribution D_2. □

Proof of Proposition 4. Notice that from $\frac{p-w}{p-c_r} = \frac{p-c}{p-c_s}$, we have $(w-c) = (c_r - c_s)\frac{p-c}{p-c_s}$ and $Q_i^* = Q_i^I$. From Eq. (11),

$$\begin{aligned}\Delta E\Pi_m &= (w-c)(Q_2^* - Q_1^*) - (c_r - c_s)\left(\int_0^{Q_2^*} F_2(x)dx - \int_0^{Q_1^*} F_1(x)dx\right) \\ &= \left(\frac{c_r - c_s}{p-c_s}\right)((p-c)(Q_2^* - Q_1^*) \\ &\quad - (p-c_s)\left(\int_0^{Q_2^*} F_2(x)dx - \int_0^{Q_1^*} F_1(x)dx\right)\Big)\end{aligned}$$

$$= \left(\frac{c_r - c_s}{p - c_s}\right)\left((p - c)\left(Q_2^I - Q_1^I\right)\right.$$
$$\left. -(p - c_s)\left(\int_0^{Q_2^I} F_2(x)dx - \int_0^{Q_1^I} F_1(x)dx\right)\right)$$
$$= \left(\frac{c_r - c_s}{p - c_s}\right)\Delta E\Pi_s.$$

Since p, c_s, and $\Delta E\Pi_s$ are independent of c_r, it follows directly from the above equation that $\Delta E\Pi_m$ is increasing in c_r.

To prove $\lim_{(w-c_r)\to 0}\Delta E\Pi_m = \Delta E\Pi_s$, it suffices to show $\lim_{(w-c_r)\to 0}\left(\frac{c_r-c_s}{p-c_s}\right) = 1$. Note that from $\frac{p-w}{p-c_r} = \frac{p-c}{p-c_s}$, we have $(w-c_r) = (p-c_r)\left(1-\frac{p-c}{p-c_s}\right)$. Since $1-\frac{p-c}{p-c_s} > 0$, as $(w - c_r) \to 0$, we must have $c_r \to p$ and consequently $\frac{c_r-c_s}{p-c_s} \to 1$. This concludes the proof. □

References

Billington, C., Lee, H.L., Tang, C.S., 1998. Successful strategies for product rollovers. Solan Management Review 39 (Spring), 23–30.

Cachon, G., Lariviere, M., 2001. Contracting to assure supply: How to share demand forecasts in a supply chain. Management Science 47, 629–646.

Chen, F., 2001. Market segmentation, advanced demand information, and supply chain performance. Manufacturing and Service Operations Management 3 (1), 53–67.

Chu, W., 1992. Demand signaling and screening in channels of distribution. Marketing Science 11 (4), 327–347.

Corbett, C.J., Tang, C.S., 1999. Designing Supply Contracts: Contract Type and Information Asymmetry. Quantitative Models of Supply Chain Management. Kluwer Academic Publishers.

Erhun, F., Goncalves, P., Hopman, J., 2007. The art of managing new product transitions. MIT Sloan Management Review 48 (3), 73–80.

Fisher, M., Raman, A., 1996. Reducing the cost of demand uncertainty through accurate response to early sales. Operations Research 44 (1), 87–99.

Gallego, G., Özer, Ö., 2001. Integrating replenishment decisions with advance demand information. Management Science 47, 1344–1360.

Gerchak, Y., Mossman, D., 1992. On the effect of demand randomness on inventories and costs. Operations Research 40 (4), 804–807.

Ha, A.Y., 2001. Supplier–buyer contracting: Asymmetric cost information and cutoff level policy for buyer participation. Naval Research LOGISTICS 48, 41–64.

Hitachi Global Storage Technologies, 2006. Competing on time. Stanford University.

Holmstrom, B., Milgrom, P., 1987. Aggregation and linearity in the provision of intertemporal incentives. Econometrica 55 (2), 303–328.

Iyer, A.V., Bergen, M.E., 1997. Quick response in manufacturer–retailer channels. Management Science 43 (4), 559–570.

Kalish, S., Mahajan, V., Müller, E., 1995. Waterfall and sprinkler new-product strategies in competitive global markets. International Journal of Research in Marketing 12, 105–119.

Karlin, S., Novikoff, A., 1963. Generalized convex inequalities. Pacific Journal of Mathematics 13, 1251–1279.

Kaya, M., Özer, Ö., forthcoming. Risk and information sharing in supply chains through pricing contracts. In: Özer, Ö., Phillips, R. (Eds.). The Oxford Handbook of Pricing Management. Oxford University Press.

Miyaoka, J., Hausman, W.H., 2008. How improved forecasts can degrade decentralized supply chains. Manufacturing and Service Operations Management 10 (3), 547–562.

Müller, A., Stoyan, D., 2002. Comparison Methods for Stochastic Models and Risks. John Wiley, West Sussex.

Nahmias, S., 2001. Production and Operations Analysis, forth ed. McGraw-Hill/ Irwin, New York, NY.

Özer, Ö., Wei, W., 2006. Strategic commitments for an optimal capacity decision under asymmetric forecast information. Management Science 52 (8), 1239–1258.

Özer, Ö., Zheng, Y., Chen, K., 2009. Trust in forecast information sharing. Working paper, Stanford University.

Pasternack, B.A., 1985. Optimal pricing and return policies for perishable commodities. Marketing Science 4 (2), 166–176.

Tirole, J., 1988. The Theory of Industrial Organization. The MIT Press, Cambridge, MA.

Tsay, A., 1999. The quantity flexibility contract and supplier–customer incentives. Management Science 45 (10), 1339–1358.

Yue, X., Raghunathan, S., 2007. The impacts of the full returns policy on a supply chain with information asymmetry. European Journal of Operational Research 180, 630–647.