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Quick Response under Competition

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We consider a manufacturer serving two competing retailers that sell their products over a single selling season. The retailers place their regular orders before the season starts. In addition to this initial order, quick response (QR) provides a retailer with an additional replenishment opportunity after demand uncertainty is resolved. The manufacturer determines the unit price for QR replenishment. We characterize the retailers' ordering, and the manufacturer's pricing decisions in equilibrium when none, only one, and both of the retailers have QR ability. We study how the profitability of the manufacturer, the retailers, and the channel depend on QR and competition. We find it may be optimal for the manufacturer to offer QR to only one of the *ex ante* identical retailers when demand variability is sufficiently, but not overly high. The manufacturer may also find it optimal to offer QR to both or none of the retailers, depending on demand variability. Finally, while QR ability is always attractive for a retailer when competition is ignored, we find QR may prove detrimental when its impact on competition is taken into account.

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1. Introduction

Quick response (QR) is an operational lever that aims to provide better response to variations in demand. One of its benefits is to enable in-season replenishment through lead time reduction. The success of QR has received much attention (Hammond and Kelly 1990), and its benefits have been studied extensively in literature (e.g., Fisher and Raman 1996, Iyer and Bergen 1997). Naturally, more and more firms have adopted QR to gain a competitive edge. For example, a burgeoning British apparel retailer, Primark, uses QR for faster product turnover, and it fetched 10.1% market share, while the market leader Marks & Spencer garnered 11.4% market share in the United Kingdom in 2008 (Vickers 2008). Nevertheless, the growing popularity of QR has also intensified competition, which can potentially diminish the value of QR. For instance, after its domestic success with quick response, the Japanese retailer Uniqlo invaded the U.S. market in 2006 (Alexander 2009), and a similar move is taken by the British retailer Topshop whose New York flagship opened in 2009 (Resto 2010). The effect of competition on QR, however, has received less attention and not been fully understood, and it is our main area of focus in this study.

Despite the extensive studies on the benefits of QR for retailers (e.g., Cachon and Swinney 2009, Caro and Martínez-de-Albéniz 2010), there has been less focus on the value of QR to a manufacturer. When should a manufacturer offer QR? What is its optimal supply chain structure? Should a manufacturer serving competing retailers offer QR? Indeed, it is not uncommon to see a manufacturer serving competing customers. For example, Hot Kiss, a California-based manufacturer serves junior fashion retailers Hot Topic and deLia's as well as upscale department stores like Dilliard's and Nordstrom (Bhatnagar 2006). Hot Kiss achieves quick response by taking advantage of local production in California. Similarly, Makalot, a leading Taiwanese apparel manufacturer serves Kohl's, Target, JC Penney, and Gap. In addition to regular deliveries, Makalot also provides faster in-season deliveries to its clients, and achieves quick response by flexible capacity allocation and improved information sharing with its clients.[1] In the footwear industry, Yue Yuen, a major sportswear manufacture that provides a shorter lead time than its competitors, supplies brand names like Nike, Puma, and Adidas (Taylor 2008).

In this study, we model a supply chain with a single manufacturer supplying homogeneous products to two competing retailers. The retailers sell their products in a consumer market with a single selling season. Prior to the selling season, the manufacturer sets the QR price for QR replenishment, and then each retailer places a regular (initial) order at an exogenous wholesale price. We allow the manufacturer to determine this price in section 6.1. After observing the actual demand, each retailer with QR ability places a second order at the QR price. Finally, the selling season starts and the retailers compete in the consumer market, following Cournot quantity competition. Quantity-based competition is appropriate for industries with long supply lead time (e.g., apparel and footwear); in these industries, price competition is less likely because it requires instant adjustment of production quantity (Feng and Lu 2010).[2] We consider three scenarios, with zero, one, and both retailers having QR ability, respectively. We derive the equilibrium for each of these scenarios and their comparison leads to a number of interesting results.

As a result of interplay between demand variability and retail competition, we find that the manufacturer may find it optimal to offer QR to only *one* of the *ex ante* symmetric retailers, rather than both of them. When a retailer attains QR ability, the tendency is to reduce the initial order quantity and use the QR order to fulfill any additional demand. The manufacturer's value of QR therefore depends on the trade-off between the initial order loss and additional QR profit gain. As demand variability decreases, the expected size of QR orders and therefore the manufacturer's QR profit decreases as well. Furthermore, due to intensifying effect on retail competition, the manufacturer's QR profit from offering QR to the second retailer is less than that of the first. Thus, when demand variability is sufficiently small, although the manufacturer's QR profit from the first retailer outweighs the profit loss in its regular orders, its QR profit from the second retailer is insufficient to compensate the profit loss in its regular order. Thus, it is more advantageous for the manufacturer to offer QR exclusively to one of the retailers. When demand variability is sufficiently large, the manufacturer offers QR to both of the retailers. Moreover, the total channel profit can also be maximized with only one retailer with QR option instead of both, as retail competition hinders the value of having a second retailer with QR option.

When retail competition is ignored, QR always benefits a retailer. Surprisingly, however, we find that in the presence of retail competition having QR ability can be detrimental to a retailer when demand variability is sufficiently small. When competing against a competitor without QR ability, the competitor increases its order quantity to compensate for its lack of QR ability by ordering a high amount, threatening to deflate the price. This in turn forces the retailer with QR option to reduce its initial order. When demand variability is small, the benefit of using QR to match additional demand is insignificant. Consequently, gaining QR ability hurts the retailer due to potential loss from the initial order. In contrast, when the demand variability is sufficiently large, QR benefits the retailer. Similarly, when competing against a competitor who already has QR ability, not having QR ability enables a retailer to force its competitor to reduce its initial order quantity. When demand variability is small, committing to such a threat as a result of not having QR ability dominates the benefit of reducing mismatch between supply and demand using QR ability.

We demonstrate that our results can continue to hold for a number of extensions by: (i) Allowing the manufacturer to set the wholesale price endogenously; (ii) Considering alternative sequence of events such as allowing the QR price to be set after retailers place their regular orders or after demand uncertainty is resolved; (iii) Considering normally distributed demand through numerical studies; and (iv) Studying the outcomes when the manufacturer has limited capacity for fulfilling QR orders. Overall, our results demonstrate how retail competition changes the value of QR, and provide managerial insights to a manufacturer's QR offering decision as well as a retailer's QR adoption decision.

These extensions also yield some additional results. Specifically, when the QR price is determined *after* the retailers place their initial orders, the manufacturer may find it optimal not to offer QR to any of the retailers. In addition, when there is limited QR capacity, the manufacturer may always find it optimal to offer QR to only one of the retailers due to capacity limit even when demand variability is sufficiently high.

The remainder of this article is organized as follows. In section 2, we present our literature review. Section 3 describes our model. Section 4 derives the equilibrium. Section 5 discusses the value of QR both from the manufacturer's and retailers' perspective. Section 6 presents several extensions to the base model. Section 7 offers our concluding remarks. We present the monopoly retailer benchmark in Appendix A, and all proofs appear in the online appendix.

2. Literature Review

Understanding the value of QR has attracted growing attention in academic circles since the early 1990s. Here, we first summarize the studies that consider QR in the monopoly setting. In their seminal paper, Fisher and Raman (1996) show how early sales information can be used to improve demand forecasts and better manage production decisions. Iyer and Bergen (1997) evaluate the effect of lead time reduction enabled by QR in a two-level supply chain, and find that QR benefits the retailer while it may be detrimental to the manufacturer. Eppen and Iyer (1997) examine the value of backup agreements. Under this agreement, a retailer can place an additional order using QR up to a certain percentage of its initial order at the original cost, but any additional order in excess of that fraction is charged a higher cost. They show that backup agreements can benefit both the retailer and the manufacturer. Cachon and Swinney (2009) identify the sufficient conditions under which QR benefits a retailer when it faces strategic consumers. Fisher et al. (2001) propose a heuristic that determines both ordering quantities and in-season replenishment time for a catalog retailer, finding this procedure offers the potential to double that retailer's profit. These studies do not consider the effect of competition, and they treat the price for QR replenishment as exogenously determined. By contrast, we study the effect of competition on the value of QR, allowing the manufacturer to set endogenously the price for QR replenishment.

While the above studies are restricted to monopoly, recently, Caro and Martínez-de-Albéniz (2010), Li and Ha (2008), and Krishnan et al. (2010) have examined the competitive value of QR. Caro and Martínez-de-Albéniz (2010) and Li and Ha (2008) focus on retailer competition like our study whereas Krishnan et al. (2010) focus on manufacturer competition. Specifically, Caro and Martínez-de-Albéniz (2010) and Li and Ha (2008) consider duopoly retailers competing for spill-over demand where consumers seek the other retailer only when their first choice retailer runs out of stock. In contrast, we adopt Cournot competition, in which inventory competition has a direct impact on the retail price. In addition, both Caro and Martínez-de-Albéniz (2010) and Li and Ha (2008) treat the retailers' cost for QR replenishment as exogenous, whereas we allow the manufacturer to set that price. This allows us to study vertical interactions between the manufacturer and the retailers in addition to horizontal retail competition. Such variances in modeling approaches also lead to different results. Assuming identical prices for all replenishment opportunities, Caro and Martínez-de-Albéniz (2010) demonstrate that QR always benefits a retailer. Similarly, Li and Ha (2008) find that a firm always benefits from having reactive capacity that enables replenishments after better demand information is observed. In contrast, we find QR may hurt a retailer when demand variability is too small.

Krishnan et al. (2010) consider a manufacturer selling its product through a retailer who also carries a competing product from another manufacturer. The retailer can exert sales effort to switch demand from one product to another. Therefore, their model studies the competition between two manufacturers' products sold by a single retailer. In contrast, we consider the competition between two retailers selling products supplied by a single manufacturer. Krishnan et al. (2010) find that QR can hurt the manufacturer's sales because it reduces the retailer's commitment to promote the product.

Quick response enables additional order placement after better demand information becomes available, and there exists a rich literature studying how firms can make use of updated demand information in their procurement decisions. Gurnani and Tang (1999) analyze a situation in which a retailer can place a second order when it receives better demand information. But at the time of the first order, the price for the second order is uncertain. Weng (2004) considers a single-buyer single-manufacturer channel in which the manufacturer is able to dictate its price for the buyer's second order. He presents a quantity discount scheme that coordinates the channel. Milner and Kouvelis (2005) study the effect of demand characteristics on the value of supply chain flexibility, which is characterized by the timing or quantity flexibility for the second ordering opportunity. Donohue (2000) shows that a buy-back contract can achieve channel coordination for a supply chain with one manufacturer supplying a single retailer. Cvsa and Gilbert (2002) examine a manufacturer's trade-off between offering early and delayed purchases. In their model, a retailer places an order either before *or* after demand uncertainty is realized, whereas we allow a retailer to place orders both before *and* after the uncertainty is resolved. In addition, Cachon (2004), Dong and Zhu (2007), and Erhun et al. (2008a) examine the impact of push, pull, and advance-purchase discount contracts. Although these models incorporate the idea of making use of updated demand information in procurement decision, only Milner and Kouvelis (2005), Erhun et al. (2008a), and Cvsa and Gilbert (2002) study the value of this ability. Moreover, only Cvsa and Gilbert (2002) consider the effect of competition.

Models with multiple ordering decisions, albeit without demand information updates, are also of particular interest to operations management. Martínez-de-Albéniz and Simchi-Levi (2007) and Erhun et al. (2008b) examine the effect of multiple procurement opportunities before an uncertain selling season starts. Both find more frequent procurement decreases double marginalization while increasing profitability for all supply chain participants. Anand et al. (2008) present a two-period model with identical deterministic demand curves and endogenous wholesale prices. They remove classical motivations and highlight strategic implications for carrying inventory. This model is extended by Keskinocak et al. (2008) to incorporate capacity limitations. Works that highlight competition with multiple ordering opportunities include Hall and Porteus (2000), Netessine et al. (2006), and Liu et al. (2007). All of these study products sold in multiple periods, whereas we are concerned with a short life cycle product that is sold over a single period. Furthermore, these works do not study the effect of improved demand information on inventory decisions.

In addition to using quick response, researchers have identified a number of operational strategies to cope with demand uncertainty. For example, a firm that produces and sells its product directly to consumers may invest in reactive capacity to allow for additional production after better demand information is obtained (e.g., Li and Ha 2008, Raman and Kim 2002). Although both QR and reactive capacity enable a second replenishment opportunity, the second replenishment is limited by the capacity level set beforehand in the case of reactive capacity. Delayed product differentiation provides firms with another instrument to respond to demand uncertainty (e.g., Anand and Girotra 2007, Lee and Tang 1997). It allows a firm to configure an intermediate good into different products after demand uncertainty is resolved, whereas QR considers a firm's ability to order additional inventory. Finally, spot trading is also another commonly used strategy and its value is studied by Mendelson and Tunca (2007). While spot trading allows retailers to trade among themselves, in our model QR only allows them to buy additional units from the manufacturer. Mendelson and Tunca (2007) show spot trading can adversely affect a firm, and similarly we find that QR ability can be harmful in a competitive environment.

3. The Model

First we introduce the demand model, followed by detailed descriptions of the firms' decisions. We consider a manufacturer supplying homogeneous products to two competing retailers, indexed by $i = 1, 2$. All firms are risk neutral and seek to maximize their individual expected profits. The retailers sell their products in an uncertain consumer market with a linear demand curve:

$$p = A - \sum_{i=1}^{2} X_i,$$

where p is the clearing price, X_i is the quantity sold by retailer i, and A is the demand state that takes values $m + v$ and $m - v$ with equal probabilities, that is, $P(A = m + v) = P(A = m - v) = 0.5$, where m is the mean demand, and v is a measure of demand variability. We also discuss what happens when A is normally distributed in section 6.4. The distribution of A is public information. We assume $0 < v < m$ to avoid non-positive demand state. We refer to $A = m + v$ as "high market," and similarly $A = m - v$ as "low market."

There are two types of retailers: slow (S) and fast (F). They differ in their ordering opportunities. A slow retailer has only one ordering opportunity: it places its regular order *before* the demand uncertainty is resolved. In addition to this initial order, a fast retailer has QR ability to place a second order *after* the demand uncertainty is resolved. Each retailer places its regular order Q_i at a wholesale price c_w per unit, and each fast retailer places its QR order q_i at a price c_q per unit. We assume the order quantities are public information, which is common in models of inventory competition (e.g., Li and Ha 2008, Netessine et al. 2006, Olsen and Parker 2008). The products are sold in a single selling season. We assume that the salvage value of the products is insignificant, and the retailers sell out all of their inventory in the selling season, that is, $X_i = Q_i + q_i$. This is a common assumption in literature (e.g., Anand et al. 2008, Chod and Rudi 2005, Goyal and Netessine 2007). Therefore, a retailer's profit π_i is given as follows. Note that $q_i = 0$ for a slow retailer i, and it only chooses Q_i.

$$\pi_i = \left(A - \sum_{j=1}^{2} (Q_j + q_j) \right) (Q_i + q_i) - c_w Q_i - c_q q_i, \quad i = 1, 2. \tag{1}$$

As Equation (1) shows, retailer i's profit consists of three parts: the first part represents retailer i's revenue; the second, its cost for the initial order; and the last part captures its cost for the QR order.

The wholesale price c_w for regular orders is exogenously determined. However, the manufacturer determines its unit price c_q for QR orders. This mimics the situation in which many other manufacturers are able to deliver the products when given sufficiently long lead time, determining that the wholesale price c_w is dictated by competition. By contrast, few other manufacturers are able to offer quick response as it requires additional capabilities. This makes it possible to dictate its QR price c_q. Note that we also study what happens when the wholesale price c_w is set endogenously in section 6.1.

The manufacturer's production cost for regular orders is normalized to zero. Because implementing QR requires additional costs (e.g., overtime expenses and more costly transportation methods) however, the manufacturer incurs a cost premium $\delta > 0$ per unit for QR replenishments. We assume $\delta < v$ to eliminate trivial cases in which the QR cost δ is so high, QR is never used. Thus, given the retailers' order quantities, the manufacturer's profit π_M is calculated as:

$$\pi_M = c_w \left(\sum_{i=1}^{2} Q_i \right) + (c_q - \delta) \left(\sum_{i=1}^{2} q_i \right). \tag{2}$$

To avoid an additional trivial case, we assume $c_w < m$. When $c_w \geq m$ the product is not feasible (i.e., no unit will be sold). This can be seen clearly from Equation (3).

Figure 1 shows the order of events: First, the manufacturer announces the QR price c_q. Retailers then place their regular orders simultaneously for delivery before the beginning of the selling season. The demand state A is revealed completely to the retailers. Next, each fast retailer places its QR order, which will also be delivered before the selling season. Finally, the selling season ensues during which the retailers sell their inventory, and profits are realized.

4. Competition

We consider three competition scenarios, denoted by *SS* (two competing slow retailers), *FS* (one fast retailer vs. one slow retailer), and *FF* (two competing fast retailers). In this section, we solve for the firms' subgame perfect Nash equilibrium (SPNE) strategies in each scenario. We will compare these scenarios to characterize the value of QR in the next section.

4.1. *SS* Scenario (Two Competing Slow Retailers)

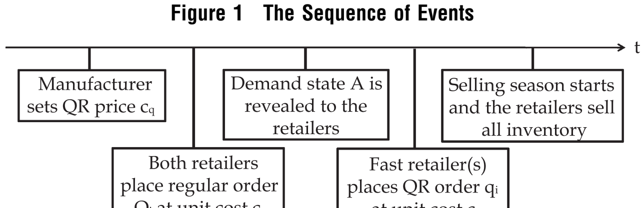
We consider the *SS* scenario as a benchmark. In this scenario, none of the retailers has QR ability, that is, each retailer can place only a single order that must be decided prior to the resolution of demand uncertainty. Consequently, this problem reduces to a single stage standard Cournot duopoly model (Tirole 1988). In this scenario, retailer i's expected profit is given by $\mathbb{E}[\pi_i]$, where $\mathbb{E}$ is the expectation with respect to the demand intercept A and π_i is given in Equation (1) with $q_1 = q_2 = 0$. It is straightforward to show that the unique equilibrium is given by:

$$Q_i = \frac{m - c_w}{3}, \quad i = 1, 2. \tag{3}$$

4.2. *FS* Scenario (a Fast Retailer vs. a Slow Retailer)

We now study competition between a fast (1) and a slow retailer (2): In this scenario, as described by the sequence of events given in Figure 1, QR ability allows the fast retailer to place an additional order after demand uncertainty is revealed. In the following, we derive the firms' equilibrium decisions by applying backward induction.

Figure 1 The Sequence of Events



In the last stage game, the demand state A is revealed to the retailers. The fast retailer determines its QR order quantity q_1 to maximize its profit π_1 that is given by Equation (1). It is straightforward to show that π_1 is concave in q_1, and, following the first order condition, retailer 1's optimal QR order quantity is given by:

$$q_1 = \left(\frac{A - c_q - Q_2}{2} - Q_1 \right)^+, \tag{4}$$

where A is the demand state, c_q is the unit QR ordering cost, and $(x)^+ = \max(0,x)$. As Equation (4) shows, retailer 1 places its QR order following a base-stock policy and the base-stock level decreases in both the QR price and the competing retailer's regular order quantity.

In the second stage game, the retailers determine their regular order quantities to maximize their expected profits $\mathbb{E}[\pi_i]$. The following lemma characterizes the retailers' equilibrium regular and QR order decisions.

Lemma 1. *There exists a unique equilibrium for the retailers' regular order quantity game in the FS scenario. The retailers' equilibrium actions are described below and the equilibrium regular order quantities are given in Appendix B.*

(*i*) *For* $\bar{\theta}^{FS} \leq c_q : Q_2 = Q_1 \geq 0$, *and retailer 1 does not place a QR order for any market outcome.*
(*ii*) *For* $\underline{\theta}^{FS} \leq c_q < \bar{\theta}^{FS} : Q_2 > Q_1 \geq 0$, *and retailer 1 places a QR order only in a high market.*
(*iii*) *For* $c_q < \underline{\theta}^{FS} : Q_2 > Q_1 = 0$, *and retailer 1 places QR orders in both high and low market outcomes, where*

$$\bar{\theta}^{FS} = c_w + v \text{ and}$$
$$\underline{\theta}^{FS} = \min\left(c_w, \frac{3}{7}m + \frac{4}{7}c_w - \frac{5}{7}v, m - v \right).$$

A higher QR price, c_q, reduces the attractiveness of QR ability. As a result, when c_q is sufficiently high, as in case (i) of Lemma 1, QR is never used and thus the retailers' behavior is identical to that of the *SS* scenario. On the other hand, QR is used only in a high market for $\underline{\theta}^{FS} \leq c_q < \bar{\theta}^{FS}$. In this case, the slow retailer places a larger regular order than its fast competitor to compensate for the lack of QR option. Finally, when $c_q < \underline{\theta}^{FS}$, the QR price is extremely low, and the fast retailer relies only on QR for inventory replenishment, it does not place a regular order.

In the first stage game, the manufacturer sets the QR price, c_q, to maximize its expected profit $\mathbb{E}[\pi_M]$. We characterize the manufacturer's optimal c_q in the following proposition:

PROPOSITION 1. *Let*

$$\beta^{FS} = \begin{cases} \frac{18m+\sqrt{21}(3m-5v+5\delta)}{36} & \text{for } v \le \frac{3}{5}m+\delta \\ m - \frac{5}{6}(v-\delta) & \text{otherwise} \end{cases}.$$

(*i*) *When* $c_w < \beta^{FS}$, *the manufacturer sets* $c_q = c_w + \frac{v+\delta}{2}$, *the retailers order* $Q_1 = \frac{3}{10}(m - c_w) - \frac{1}{4}(v-\delta), Q_2 = \frac{m-c_w}{5}$.

(*ii*) *When* $c_w \ge \beta^{FS}$, *the manufacturer sets* $c_q = \min(\frac{8c_w - 3m}{5} + v, \frac{3m + 8c_w + 7(v+\delta)}{14})$, *the retailers order* $Q_1 = 0, Q_2 = (\frac{45m - 48c_w - 7(v-\delta)}{48})^+$. *In both cases, the fast retailer places a QR order only in a high market, and its QR order quantity is given by Equation (4).*

When $c_w \ge \beta^{FS}$, the wholesale price is extremely high and this results in a trivial case, where the fast retailer never places a regular order, whereas when $c_w < \beta^{FS}$ both retailers place a regular order. In comparison to the *SS* scenario, Equation (3) and Proposition 1 show the fast retailer chooses a smaller regular order quantity because it has a second replenishment opportunity.

4.3. *FF* Scenario (Two Competing Fast Retailers)

The *FF* scenario concerns competition between two fast retailers. Here both retailers can place a QR order after the market uncertainty is resolved, as shown in Figure 1. We derive the firms' equilibrium decisions by applying backward induction. In the last stage game, the retailers determine their QR order quantities. It is straightforward to show that each retailer *i*'s profit, as given in Equation (1), is concave in its QR order quantity q_i. Therefore, retailer *i*'s best response QR order quantity, q_i^{BR}, can be derived using the first order condition:

$$q_i^{BR}(A, Q_i, Q_j, q_j) = \left(\frac{A - c_q - q_j - Q_j}{2} - Q_i \right)^+,$$

where, $i = 1, 2$ and $j = 3 - i$. Without loss of generality, we assume that retailer *i* places a larger regular order, that is, $Q_i \ge Q_j$. Let q_i^{FF} be retailer *i*'s equilibrium QR order quantity in the *FF* scenario. By using the fact that the equilibrium should satisfy $q_i^{BR}(A, Q_i, Q_j, q_j^{FF}) = q_i^{FF}$, we obtain the following equilibrium QR order quantity pair:

$$(q_i^{FF}, q_j^{FF}) = \begin{cases} (\frac{A-c_q}{3} - Q_i, \frac{A-c_q}{3} - Q_j), & \text{if } A - c_q \ge 3Q_i \\ (0, (\frac{A-c_q-Q_i}{2} - Q_j)^+), & \text{otherwise} . \end{cases} \quad (5)$$

Thus, a retailer places a QR order only when its regular order quantity Q_i relative to the demand A is sufficiently small.

In the second-stage game, the retailers determine their regular order quantities simultaneously to maximize their expected profits prior to observing the actual demand state. The following lemma describes the retailers' equilibrium actions:

LEMMA 2. *There exists a unique equilibrium for the retailers' regular order quantity game in the FF scenario. In equilibrium,* $Q_1 = Q_2$ *and they are given in Appendix B. The retailers' equilibrium actions are given below:*

(*i*) *For* $\bar{\theta}^{FF} \le c_q$: *the retailers do not place a QR order for any market outcome.*

(*ii*) *For* $\underline{\theta}^{FF} \le c_q < \bar{\theta}^{FF}$: *the retailers place QR orders only in a high market.*

(*iii*) *For* $c_q < \underline{\theta}^{FF}$: $Q_1 = Q_2 = 0$, *and the retailers place QR orders in both high and low markets, where*

$$\bar{\theta}^{FF} = c_w + v \text{ and } \underline{\theta}^{FF} = \min(c_w, m - v).$$

Note that Lemma 2 is structurally similar to Lemma 1. In the *FS* scenario, Lemma 1 establishes the slow retailer initially orders more than its fast counterpart due to asymmetric QR ability. In contrast, Lemma 2 shows the retailers choose equal regular order quantities in the *FF* scenario as both of them have symmetric QR ability.

In the first-stage game, the manufacturer sets its QR price to maximize its expected profit $\mathbb{E}[\pi_M]$. The following proposition summarizes the equilibrium.

PROPOSITION 2. *Let*

$$\beta^{FF} = \begin{cases} \frac{m+\sqrt{v^2+2m\delta-2v\delta}}{2} & \text{for } v \le (\sqrt{2}-1)(m-\delta) \\ \frac{2m+\sqrt{2}(m-v+\delta)}{4} & \text{otherwise} \end{cases}.$$

(*i*) *When* $c_w < \beta^{FF}$, *the retailers order* $Q_1 = Q_2 = \frac{m-c_w}{3} - \frac{1}{6}(v-\delta)$, *the manufacturer sets* $c_q = c_w + \frac{v+\delta}{2}$, *and the retailers place QR orders only in a high market.*

(*ii*) *When* $c_w \ge \beta^{FF}$, *the retailers choose* $Q_1 = Q_2 = 0$,

a. *for* $v \le (\sqrt{2}-1)(m-\delta)$, *the manufacturer sets* $c_q = \frac{m+\delta}{2}$, *and the retailers place QR orders in both high and low markets.*

b. *for* $v > (\sqrt{2}-1)(m-\delta)$, *the manufacturer sets* $c_q = \frac{m+v+\delta}{2}$, *and the retailers place QR orders only in a high market.*

In all cases retailers' QR order quantities are given by Equation (5).

Retailer behavior in the *FF* scenario is similar to that of the fast retailer in the *FS* scenario—they place regular orders only when the wholesale price, c_w, is not extremely high. In this case, the retailers place QR orders if the market turns out to be high, but do not place any QR order if the market turns out to be low. Also, Equation (3) and Proposition 2 show a fast retailer in the *FF* scenario chooses a smaller regular order quantity due to QR, in comparison to the *SS* scenario. With a solid understanding of the firms' equilibrium actions, we proceed to evaluate the value of QR.

5. The Value of QR

Here we study the impact of having QR ability on the profitability of all channel participants. This allows us to address numerous questions of managerial interest, including: Should the manufacturer offer QR ability to all, some, or none of the retailers? How does retail competition affect the value of QR? Does QR improve the performance of the supply chain as a whole? What is the impact of demand uncertainty? Section 5.1 considers the monopoly retailer benchmark. Sections 5.2, 5.3, and 5.4 consider duopoly competition and explore the value of QR for the manufacturer, the retailers, and the whole channel.

5.1. Monopoly Retailer Benchmark

To tease out the effect of competition, we first consider a monopoly retailer. We will contrast monopoly and duopoly results to understand the effect of retail competition. When the manufacturer serves a monopoly retailer, the firms' pricing and ordering decisions are described in Appendix A. Let Π_R^a and Π_M^a be the expected equilibrium profits for the monopoly retailer and the manufacturer, respectively, when the retailer is type a, where $a = F,S$ stands for fast and slow. The following proposition summarizes the effect of QR on the profitability of the manufacturer, the retailer, and the channel:

PROPOSITION 3.

(*i*) $\Pi_M^F > \Pi_M^S$.
(*ii*) $\Pi_R^F > \Pi_R^S$.
(*iii*) $\Pi_M^F + \Pi_R^F > \Pi_M^S + \Pi_R^S$.

Proposition 3 shows that QR increases the profitability of the manufacturer, the monopoly retailer, and the entire channel. This is intuitive, because both the manufacturer and the retailer can always match their no-QR profit. The manufacturer can nullify QR options by setting a sufficiently high QR price c_q. Similarly, the monopoly retailer utilizes QR only if it will increase profitability.

5.2. Impact of QR on the Manufacturer's Equilibrium Profit

Next we turn our attention back to duopoly retailers. For example, how many retailers should receive QR offers from the manufacturer? Most strikingly, we find that offering QR ability to only one of the *ex ante* symmetric retailers may be the optimal choice. Let Π_M^{ab} show the manufacturer's expected equilibrium profit when retailers 1 and 2 are types a and b, where $a,b = F,S$. We define thresholds for demand variability parameter v to illustrate our results in this section, these thresholds are displayed in Table C1 in Appendix C.

The following proposition identifies the supply chain configuration that maximizes the manufacturer's profit:

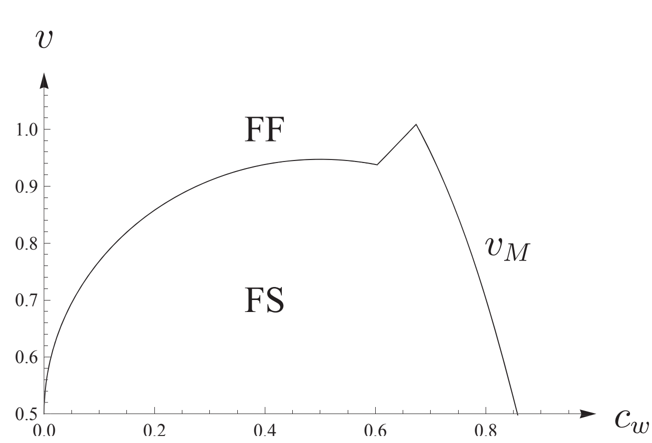
PROPOSITION 4.

(*i*) *For* $v \leq v_M$, $\Pi_M^{FS} \geq \Pi_M^{FF} > \Pi_M^{SS}$.
(*ii*) *For* $v > v_M$, $\Pi_M^{FF} > \Pi_M^{FS} > \Pi_M^{SS}$.

Figure 2 illustrates the optimal scenario for the manufacturer as Proposition 4 describes for $m = 1$ and $\delta = 0.5$. Note that the shape of v_M boundary in the figure depends on $c_w \gtreqless \beta^{FS}, \beta^{FF}$ following Propositions 1 and 2.

A retailer with QR option decreases its regular order as seen in Propositions 1 and 2. Furthermore, the expected size of the QR order decreases as demand variability gets smaller. The manufacturer exchanges loss from regular orders for gain from QR orders which increases in demand variability. When demand variability is high, as in case (ii), the manufacturer prefers offering QR to both retailers. When it is small, however, as in case (i), surprisingly, the manufacturer is better off by offering QR ability to only one of the retailers as opposed to both of them, because the *FS* scenario generates a larger profit for the manufacturer from regular orders than the FF scenario. In this case, such profits outweigh the additional QR profit for the manufacturer in the FF scenario. Due to retail competition, the manufacturer's QR profit from the addition of a second fast retailer (FS to FF) is smaller than that of the first (SS to FS). Thus, even when QR profit from the first fast retailer

Figure 2 The Scenarios that Maximize the Manufacturer's Profit for $m = 1$, $\delta = 0.5$



(SS to FS) outweighs the profit loss in its regular orders, QR profit from the second (FS to FF) may not be sufficient to compensate the profit loss in its regular order. Finally, the FS scenario always yields a higher profit than the SS scenario as the manufacturer sets the QR price endogenously: it can always nullify QR option through pricing.

In sum, the manufacturer does not always benefit from offering QR to both of the retailers. This is in contrast to the monopoly benchmark in section 5.1, where the manufacturer always benefits from offering QR to the monopoly retailer. Our results in Propositions 3 and 4 demonstrate the manufacturer's optimal policy critically depends on (i) the competition in retail market (monopoly vs. duopoly), (ii) the demand variability, (iii) its wholesale price for regular orders (dictated by the level of competition in the supply market), and (iv) the cost premium for QR replenishments.

5.3. Impact of QR on the Retailers' Equilibrium Profits

Turning to the impact of QR on retailer equilibrium profits, we now explore the value of QR for a retailer under competition. Let Π_i^{ab} be retailer i's expected equilibrium profit when retailers 1 and 2 are types a and b respectively, where $i = 1,2$ and $a,b = F,S$. The following proposition describes a retailer's value of QR as well as the impact of gaining QR ability on the competitor's profitability. It shows having QR ability can be detrimental to a retailer while benefiting its competitor. (All of the threshold values used in this section are provided in Table C1 in Appendix C.)

PROPOSITION 5.

(*i*) $\Pi_1^{FS} < \Pi_1^{SS}$ *if and only if* $v < v_1^S$, *and* $\Pi_1^{FF} < \Pi_1^{SF}$ *if and only if* $v < v_1^F$, *furthermore* $v_1^S \geq v_1^F$.
(*ii*) $\Pi_2^{FS} > \Pi_2^{SS}$, *and* $\Pi_2^{FF} > \Pi_2^{SF}$ *if and only if* $v < v_2^F$.
(*iii*) $\Pi_1^{FS} < \Pi_2^{FS}$ *if and only if* $v < v^{FS}$.

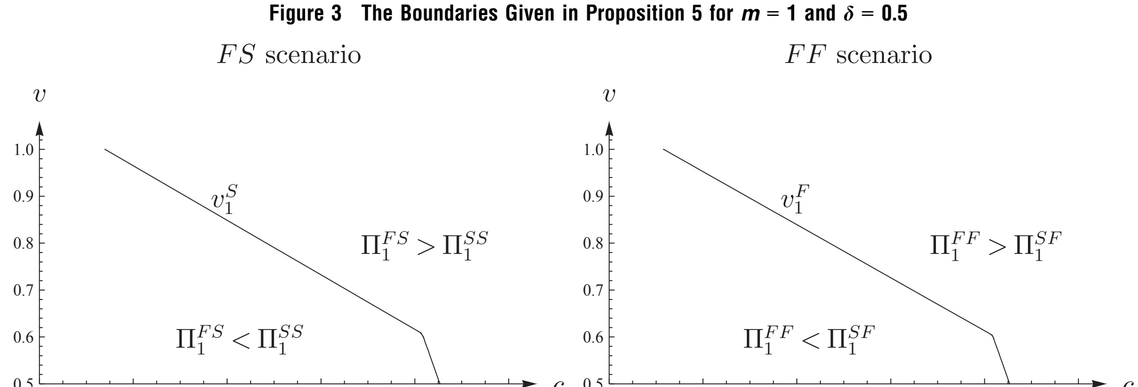
Contrary to basic intuition, Proposition 5(i) demonstrates having QR ability can hurt a retailer regardless of its competitor's type when demand variability is sufficiently small (Figure 3), due to the impact of QR ability on the competitor's actions. For intuition, consider a fast retailer, Retailer A (who has QR option), competing against a slow retailer, Retailer B (who does not). Acquiring QR option can be harmful to Retailer A in this case, because the slow competitor, Retailer B, can credibly threaten to deflate the price by ordering a high amount to compensate its lack of QR opportunity. Deflation of the price forces Retailer A to reduce its regular order quantity. When demand variability is low, there is little to be gained from a QR order, and thus, Retailer A's loss due to regular orders dominates, making QR ability harmful.

By the same token, when demand variability is high, mismatch between supply and demand is also high, and Retailer B benefits from having QR ability even if this means giving up forcing the fast competitor to reduce its regular order quantity. Note that Proposition 5(i) also shows $v_1^S \geq v_1^F$. For QR to be beneficial, a higher level of demand variability is required when competing against a slow competitor compared to a fast competitor. In other words, a retailer whose competitor already has QR option is more likely to benefit from having QR opportunity compared to a retailer whose competitor does not have QR option.

Ignoring competitive factors, our monopoly benchmark and existing work show that QR always benefits the retailer (e.g., Fisher et al. 1997, Iyer and Bergen 1997). In contrast, Proposition 5 demonstrates how competition can actually make QR unattractive to a retailer.

In addition, part (ii) of Proposition 5 shows when a retailer gains QR ability, it can actually benefit its slow competitor. In particular, a slow competitor always fares better as it enjoys a larger order quantity over the fast retailer. Fast competitor only fares better if demand variability is small. Likewise, if both firms have QR opportunity, the competition in a high market is intensified and this makes the fast competitor fare worse when demand variability is high. In

Figure 3 The Boundaries Given in Proposition 5 for m = 1 and δ = 0.5



addition, part (iii) of Proposition 5 compares the retailers' profits in the *FS* scenario, showing the slow retailer achieves a higher profit only when the demand variability is sufficiently low.

Comparing Propositions 4 and 5 also reveals that when a retailer is given QR option, this can benefit all supply chain members. In particular, all of the firms are strictly better off in the *FS* scenario than in the *SS* scenario when $v_1^S < v$. In the next proposition, we describe what happens when both of the retailers gain QR ability simultaneously:

Proposition 6. $\Pi_i^{FF} > \Pi_i^{SS}$ *for* $i = 1, 2$.

Proposition 6 shows that both retailers reap greater benefits if both gain QR ability simultaneously. When they all have QR opportunity, no retailer can threaten to place a higher regular order quantity.

One might wonder what the equilibrium would be if retailers choose to adopt QR themselves rather than having it dictated to them by the manufacturer. This is studied in detail in Appendix S1. We find that the equilibrium is always symmetric, either both (FF) or none (SS) of the retailers choose to adopt QR. Specifically, when demand variability is low, none of the retailers adopt QR (SS), when demand variability is high, both of them adopt QR (FF), and when demand variability is moderate both SS and FF scenarios can be equilibria.

5.4. Impact of QR on the Channel's Equilibrium Profit

Next, we analyze which channel configuration, namely the number of fast retailers, is the most profitable for the entire channel. Let Π_C^{ab} be the expected channel profit in equilibrium, that is, the total expected profit achieved by the manufacturer and both of the retailers in equilibrium when retailers 1 and 2 are types *a* and *b* respectively, *a*,*b* = *F*,*S*:

$$\Pi_C^{ab} = \Pi_M^{ab} + \sum_{i=1}^{2} \Pi_i^{ab}.$$

The following proposition compares the expected channel profits across the three scenarios.

Proposition 7. $\Pi_C^{FF} \geq \max(\Pi_C^{FS}, \Pi_C^{SS})$ *for* $v \geq v_C$, *and* $\Pi_C^{FS} > \max(\Pi_C^{FF}, \Pi_C^{SS})$ *otherwise.*

Propositions 4 and 5 demonstrate QR ability benefits the manufacturer and the retailers when the demand variability is sufficiently high but can be detrimental when it is low. Proposition 7 is in agreement. This is intuitive, since the channel profit is the sum of the manufacturer's and retailers' profits. Proposition 7 shows the channel profit is maximized with two fast retailers when demand variability is sufficiently high, otherwise the channel might be better off with only one fast retailer.

Overall, the expected channel profit can be maximized by granting QR options exclusively to a single retailer. In contrast to the monopoly benchmark where having a QR retailer always benefits the entire channel, retail competition extends the optimal channel configuration to a continuum: the total channel profit may be maximized by having one or two retailers with QR ability.

6. Extensions

We now consider a number of extensions to our base model that suggest our key insights continue to hold in various settings, and illustrate the robustness of our results.

6.1. Endogenous Wholesale Price

First, we extend the base model given in section 3 by allowing the manufacturer to dictate the wholesale price at the beginning of the timeline.[3] Specifically, now it chooses the wholesale price c_w to maximize its expected profit in equilibrium. In the following, we present the optimal wholesale price the manufacturer would choose, then discuss the value of QR.

Lemma 3. *Suppose the manufacturer can dictate the wholesale price, it chooses* $c_w = \frac{m}{2}$ *to maximize its expected profit in all scenarios (SS, FS, and FF).*

Knowing the manufacturer's choice of the wholesale price, we are able to derive the firms' equilibrium profits in each scenario. Comparing these profits across scenarios reveals the firms' value of QR as the following proposition summarizes.

Proposition 8.

(*i*) $\Pi_M^{FS} > \Pi_M^{FF}$ *if and only if* $v < \bar{v}_M$, *and* $\Pi_M^{SS} < \max(\Pi_M^{FS}, \Pi_M^{FF})$.
(*ii*) *a.* $\Pi_1^{FS} < \Pi_1^{SS}$ *if and only if* $v < \bar{v}_1^S$, *and* $\Pi_1^{FF} < \Pi_1^{SF}$ *if and only if* $v < \bar{v}_1^F$, *furthermore* $\bar{v}_1^S > \bar{v}_1^F$.
b. $\Pi_2^{FS} > \Pi_2^{SS}$; $\Pi_2^{FF} > \Pi_2^{SF}$ *if and only if* $v < \bar{v}_C$.
(*iii*) $\Pi_C^{FS} > \Pi_C^{FF}$ *if and only if* $v < \bar{v}_C$, *and* $\Pi_C^{SS} < \max(\Pi_C^{FS}, \Pi_C^{FF})$.

The threshold values $\bar{v}_M$, $\bar{v}_1^F$, $\bar{v}_1^S$, *and* $\bar{v}_C$ *are provided in Appendix D.*

Proposition 8 shows our results in section 5 continue to hold when the manufacturer is able to choose the wholesale price in addition to the QR price. Specifically, Proposition 8(i) extends Proposition 4, showing the manufacturer's optimal policy is to offer QR to only one of the retailers when demand variability is low. Proposition 8(iia) and (iib) echo Proposition 5.

They demonstrate how QR ability can hurt a retailer when demand variability is sufficiently low, and gaining QR can actually benefit the competing retailer. Finally, Proposition 8(iii) mimics Proposition 7 showing that the total channel profit can be maximized by having only one QR-enabled retailer when demand variability is small.

6.2. Alternative Sequence of Events

In our base model, the QR price is set at the beginning of the timeline before the retailers place their regular orders. Here, we discuss two alternative models with regard to timing of the QR price and analyze the value of QR for the manufacturer, the retailers, and the channel as a whole. Specifically, we consider the following models:

($E1$): The QR price is set after the regular orders are placed, but before the realization of demand uncertainty.

($E2$): The QR price is set after the demand uncertainty is resolved. The remaining events are the same as our base model.

Models $E1$ and $E2$ actually yield identical equilibrium outcomes in our setup. This is because of the binary nature of demand distribution. In particular, in equilibrium, a fast retailer places a QR order only in a high market. Therefore, the manufacturer always sets the QR price for a high market, and the timing of the QR price (whether before or after demand realization) becomes irrelevant.

We impose an additional assumption, $c_w \leq \delta$, in this subsection. If this assumption is violated, it demonstrates the manufacturer's chosen QR price would be smaller than the wholesale price (i.e., $c_q < c_w$).[4] Thus, retailers always place QR orders regardless of the demand outcome, which is inconsistent with practice. Furthermore, relaxing this assumption creates a region with no pure-strategy equilibrium in the FS scenario, which would complicate our analysis.

The following proposition summarizes the firms' equilibrium actions for the models $E1$ and $E2$.

PROPOSITION 9. *For the models* $E1$ *and* $E2$:

(*i*) *The FS scenario has a unique equilibrium in which* $Q_1 \leq Q_2$ *and*
  a. *For* $v \leq \varepsilon_1$, *the fast retailer does not place a QR order for any market outcome.*
  b. *For* $v > \varepsilon_1$, *the fast retailer places a QR order only in a high market and it does not place a QR order in a low market.*

(*ii*) *The FF scenario has a unique equilibrium only for* $v \leq \varepsilon_1$ *and* $v \geq \varepsilon_2$, *but there does not exist a pure-strategy equilibrium for* $\varepsilon_1 < v < \varepsilon_2$. *When the equilibrium exists,* $Q_1 = Q_2$ *and*
  a. *for* $v \leq \varepsilon_1$, *the retailers do not place a QR order for any market outcome.*
  b. *for* $v \geq \varepsilon_2$, *the retailers place QR orders only in a high market and they do not place any QR order in a low market.*

The threshold values ε_1 *and* ε_2 *are given in Appendix D.*

Note that the *SS* scenario in $E1$ and $E2$ models is same as our base model—QR is not offered and thus QR price is not relevant. When the retailers have QR ability, Proposition 9 shows QR is only used in a high market as in the base model. Notice, however, a pure-strategy equilibrium in the *FF* scenario for $\varepsilon_1 < v < \varepsilon_2$ does not exist, because having the QR price set after the regular orders are placed results in piecewise concave profit functions for the retailers. Retailer profit functions may contain multiple maxima, which leads to discontinuity in the retailers' best response functions.

Building on Proposition 9, we characterize the value of QR for the manufacturer, retailers, and the entire channel in Appendix E. These are formally stated in Propositions 11–13 in that appendix. We find that our results of the base model continue to hold even when the QR price is determined after retailers place their regular orders. In particular, the profits of the manufacturer and the entire channel can still be maximized by granting QR ability to only one of the retailers, rather than both of them (Propositions 11 and 13). Furthermore, having QR ability can still be detrimental to a retailer while benefitting the opponent (Proposition 12).

We also find additional results. In models $E1$ and $E2$, the manufacturer may find it optimal not to offer QR at all when the demand variability is too low (Proposition 11). In contrast, in our base model, the QR price is set at the beginning of the timeline and the manufacturer enjoys the first mover advantage, consistently offering QR to at least one of the retailers (Proposition 4). When the QR price is set after retailers place regular orders, the manufacturer loses the first mover advantage, and this reduces the value it can extract from the retailers due to QR. Similarly, the total channel profit can also be maximized with no QR-enabled retailer at all (Proposition 13). Finally, we compare retailers' profitability in our base and $E1$ and $E2$ models in Proposition 14 in Appendix E. We find that demand variability is the key factor; competing fast retailers are better off in models $E1$ and $E2$ if and only if demand variability is sufficiently small.

6.3. Limited QR Capacity

In this section, we study what occurs when the manufacturer has limited QR capacity to grant. Specifically, we assume the manufacturer can fulfill at most

k units using QR. When the retailers' total QR order quantity exceeds the manufacturer's QR capacity, the manufacturer allocates its capacity evenly among the retailers. Any unused capacity by one retailer can be reallocated to the other retailer. In addition to the assumptions for the base model, we further restrict our analysis to $k < (m - \delta)/6$ to ensure the QR capacity is indeed limited and binds in both FS and FF scenarios. Moreover, given any QR capacity level k, we focus only on $c_w < m - 5k/3$ to eliminate the unrealistic scenario in which retailers do not place a regular order due to a high wholesale price. We derive SPNE for *FF* and *FS* scenarios and subsequently examine the value of QR. The following proposition summarizes the effect of limited capacity on the value of QR.

PROPOSITION 10. *When the manufacturer has a total capacity* k *for QR replenishment:*

(*i*) *Manufacturer:*
  a. $\Pi_M^{FF} > \max(\Pi_M^{FS}, \Pi_M^{SS})$ *for* $c_w < \tilde{w}_M$ *and* $v > \tilde{v}_M$.
  b. $\Pi_M^{FS} > \max(\Pi_M^{FF}, \Pi_M^{SS})$ *otherwise.*

(*ii*) *Retailers:*
  a. $\Pi_1^{FS} > \Pi_1^{SS}$ *if and only if* $c_w > \tilde{w}_1^S$ *and* $v > \tilde{v}_1^S$; $\Pi_1^{FF} > \Pi_1^{SF}$ *if and only if* $c_w > \tilde{w}_1^F$ *and* $v > \tilde{v}_1^F$.
  b. *The imposition of QR capacity limit increases (weakly) the regular order size of a fast retailer.*

(*iii*) *Channel:*
  a. $\Pi_C^{FS} > \max(\Pi_C^{FF}, \Pi_C^{SS})$ *for* $c_w > \tilde{w}_C$.
  b. $\Pi_C^{FF} > \max(\Pi_C^{FS}, \Pi_C^{SS})$ *otherwise.*

Note that all of the threshold values are summarized in Appendix D.

Imposing QR capacity limit induces a fast retailer to increase (weakly) the size of its regular order. We find our key insights continue to hold for this extension. This extension also yields an additional insight. In our main model without the capacity limitation, the manufacturer prefers having two fast retailers when demand variability is sufficiently high (Proposition 4). With limited QR capacity, Proposition 10(i) implies having only one fast retailer maximizes the manufacturer's profit when the wholesale price is sufficiently high (i.e., $c_w \geq \tilde{w}_M$). This result shows that the QR capacity limit can be also another reason for not offering QR option to both of the retailers. Intuitively, given a high wholesale price, a fast retailer with QR option decreases its initial order and relies more heavily on its QR order. In this case, however, the manufacturer does not have sufficient capacity to satisfy QR orders of two fast retailers. Thus, the manufacturer is better off by offering QR option to only one of the retailers, which alleviates the reduction in their initial order quantities.

6.4. Numerical Study: Normally Distributed Demand

In this section, we use computational studies to explore an alternative demand distribution. Specifically, we allow the demand intercept A to follow a truncated normal distribution with mean 1 and standard deviation σ. We consider all combinations of the following parameters:

$$c_w \in \{0.1, 0.2, 0.3, 0.4, 0.5\},$$
$$\delta \in \{0.02, 0.04, 0.06, 0.08\},$$
$$\sigma \in \{0.1, 0.2, 0.3, 0.4, 0.5\}.$$

For each parameter combination (c_w,δ,σ), we numerically search for the firms' equilibrium decisions in the *SS*, *FS*, and *FF* scenarios, that is, when there are zero, one, and two fast retailers respectively, and this generates a total of 300 instances for our study.

We define the value of QR (VQR) for a retailer as the percentage increase in its profit after adopting QR. Specifically, it is given by

$$\frac{\Pi_1^{Fb} - \Pi_1^{Sb}}{\Pi_1^{Sb}} \times 100\%, \quad b = F, S, \tag{6}$$

where Π_1^{Fb} is retailer 1's equilibrium profit when the competitor's type is b. Similarly, we define the value of QR for the manufacturer and the entire channel as the percentage increase in their profits compared to the *SS* scenario, which is given by

$$\frac{\Pi_i^{Fb} - \Pi_i^{SS}}{\Pi_i^{SS}} \times 100\%, \quad b = F, S \quad \text{and} \quad i = M, C, \tag{7}$$

where Π_i^{Fb} and Π_i^{SS} are the equilibrium profits of the manufacturer (M) or the channel (C) in the scenarios *Fb* and *SS* respectively.

We find our key results continue to hold in our numerical studies. Table 1 reports our findings for c_w = 0.2, 0.3 and δ = 0.02, which is representative, and other parameter combinations considered in our studies also yield similar results. As expected, Table 1 shows the value of QR for the retailers and the manufacturer increases in the demand standard deviation σ. For c_w = 0.3, the manufacturer prefers having only one fast retailer (*FS*) when $\sigma \leq 0.3$, and two fast retailers (*FF*) otherwise. In other words, the manufacturer's optimal policy is to offer QR to only one of the retailers when the demand variability is not sufficiently high. Similarly, Table 1(a) also demonstrates the total channel profit can be maximized with only one QR-enabled retailer when demand variability is not sufficiently high ($\sigma \leq 0.4$ for c_w = 0.3). Furthermore, Table 1(a) shows the manufacturer and entire channel are always better off offering QR to at least one of the

Table 1 Value of QR for c_w = 0.2,0.3 and δ = 0.02

	(a) Manufacturer and Channel VQR (%) in Equation (7)								(b) Retailer VQR (%) in Equation (6)			
	Manufacturer				Channel				Competitor type			
	$c_w = 0.2$		$c_w = 0.3$		$c_w = 0.2$		$c_w = 0.3$		$c_w = 0.2$		$c_w = 0.3$	
σ	*FS*	*FF*	*FS*	*FF*	*FS*	*FF*	*FS*	*FF*	*S*	*F*	*S*	*F*
0.1	10.71	0.23	9.43	0.33	3.56	0.23	2.12	0.12	−30.92	−10.33	−31.12	−11.32
0.2	11.52	3.22	10.83	3.28	4.68	2.30	4.32	1.45	−9.75	−4.37	−9.54	−6.75
0.3	14.88	9.02	13.31	6.52	7.85	5.51	7.28	3.23	5.24	2.56	11.12	−2.83
0.4	16.30	16.10	15.31	19.74	16.48	13.97	14.33	13.31	11.40	4.81	22.29	5.42
0.5	23.74	26.87	22.54	25.53	22.80	23.87	22.43	25.79	28.84	13.46	30.42	15.74

retailers. Moreover, Table 1(b) confirms having QR ability can hurt a retailer if the demand variability is not sufficiently high: Adopting QR hurts a retailer when $\sigma \leq 0.2$.

7. Conclusions

In this study we examine the value of QR under retail competition. For this purpose, we consider a market served by two competing retailers and compare the equilibrium profits for the manufacturer, the retailers, and the entire supply chain as a whole, when QR is available to one, both, or none of the retailers. We allow the manufacturer to set the prices for regular and QR replenishments. We also consider a higher cost for implementing QR, thereby quantifying the trade-off between benefits and additional costs of QR.

We demonstrate offering QR ability to a retailer may harm the manufacturer when the demand variability is not sufficiently high. In particular, we find a manufacturer may find it attractive to offer QR to only one of the *ex ante* symmetric retailers. This happens because a retailer reduces its regular (initial) order quantity when it can place a QR order. Furthermore, when the demand is not sufficiently volatile, offering QR can generate insufficient QR profit to balance the loss that results from a retailer's reduction in its regular order. Moreover, the manufacturer's additional QR profit gain from offering QR to the second retailer is less than that from the first retailer, as a consequence of retail competition. Therefore, the manufacturer does not necessarily benefit from having two retailers with QR ability. The total channel profit can also be maximized with only one retailer with QR ability, instead of two, when demand variability is not sufficiently high.

We also highlight the potential strategic peril of QR ability for a retailer in the presence of retail competition. As expected, QR ability benefits a monopoly retailer with better response to variation in demand. However, retail competition undermines the value of QR, and obtaining QR ability can actually harm a retailer when the demand variability is low and we explicitly characterize when this happens.

We recognize our model has several limitations. We assume retailers who aim to maximize their expected profits are risk neutral. Unlike a regular order, a QR order faces no demand risk, thus it has a lower risk than a regular order. A risk-averse retailer will be more inclined to use QR to decrease its demand risk. We expect a risk-averse retailer to increase its allocation of QR order (and hence decrease its allocation of regular order), making QR more valuable than our model predicts. Quantifying the impact of risk-aversion on the value of QR could be a fruitful avenue for future work. Furthermore, our model assumes QR lead time is relatively short compared to the selling season. However, this lead time can be significant and also later arriving units may suffer from drops in sales price over the selling season. These factors will degrade the attractiveness of QR and firms will shift their allocations from QR to regular orders. Thus, when such factors are accounted, we expect the outcome to fall between our fast (QR) and slow (no QR) firm scenarios. Nonetheless, our model cannot fully address these extensions, and it would be worthwhile to generalize our setting to a multi-period model to allow for long QR lead time and declining prices and study their impact.

We study a single supplier serving two retailers. While this is not uncommon in practice (introduction provides some examples), we recognize other supply chain scenarios are possible; for example, a retailer having multiple suppliers, or each retailer having a distinct supplier and so on, and some of our results may not apply to these scenarios. Thus, future work can study the impact of supply chain configuration on the value of QR considering various scenarios. Furthermore, our numerical study in section 6.4 suggests that our results can continue to hold for other more general demand distribution functions; however, showing this extension analytically would be worthwhile for future work. We also note that, in practice, retailers may not observe each other's order quantities. In this case, the manufacturer's pricing would provide a signal about order quantities and retailers would choose their best actions accordingly. Additionally, our model assumes the manufacturer incurs an identical unit QR cost δ for each retailer, making it indifferent between them. In practice, however, due to geographic dispersion, one retailer may actually result in a higher expediting cost, and thus the manufacturer may prefer offering QR to the less costly retailer. Finally, generalizing our duopoly model to oligopoly retailers is another possible extension. We expect with many competitors, reactions to a retailer's gaining of QR ability may not be as strong, thus, a retailer may be more likely to benefit from QR in an oligopoly.

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Appendix A: Monopoly Retailer Benchmark

Let q^H and q^L be the QR order quantities for the monopoly retailer in the high and low markets respectively. The following lemma characterizes the supply chain participants' equilibrium strategies:

LEMMA 4.

(*i*) *When the monopoly retailer does not have QR ability, the unique equilibrium order quantity for the retailer is* $Q = \frac{m-c_w}{2}$.

(*ii*) *When the monopoly retailer can place a QR order, there exists a unique equilibrium as follows:*

(*a*) *For* $c_w \leq c_F$: $Q = \frac{m - v - 2c_w + c_q}{2}$, $c_q = \frac{2c_w + v + \delta}{2}$, $q^H > 0$ *and* $q^L = 0$.

(*b*) *For* $c_w > c_F$: $Q = 0$, $q^H \geq 0$, $q^L \geq 0$ *and*

1. *For* $v \leq \frac{m-\delta}{2}$: $c_q = \frac{m+\delta}{2}$.
2. *For* $\frac{m-\delta}{2} < v$: $c_q = m - v$.

Appendix B: Addendum to Lemmas

LEMMA 1: *This lemma describes the retailers' equilibrium actions after* c_q *is chosen in the FS scenario. The following describes their equilibrium regular order quantities:*

(*i*) *For* $\bar{\theta}^{FS} \leq c_q$: $Q_1 = Q_2 = \frac{m - c_w}{3}$.

(*ii*) *For* $\underline{\theta}^{FS} \leq c_q < \bar{\theta}^{FS}$:

$$(Q_1, Q_2) = \left(\frac{3m - 5v - 8c_w + 5c_q}{10}, \frac{2(m-c_w)}{5}\right)$$

for $c_w \leq \alpha_1$; $(Q_1, Q_2) = \left(0, \frac{3m - v - 4c_w + c_q}{6}\right)$ *for* $\alpha_1 < c_w \leq \alpha_2$; $(Q_1,Q_2) = (0,0)$ *otherwise, where* $\alpha_1 = \frac{3m - 5v + 5c_q}{8}$ *and* $\alpha_2 = \frac{3m - v + c_q}{4}$.

(*iii*) *For* $c_q < \underline{\theta}^{FS}$: $(Q_1, Q_2) = \left(0, \frac{m + c_q}{2} - c_w\right)$.

LEMMA 2: *This lemma describes the retailers' equilibrium actions after* c_q *is chosen in the FF scenario. The following describes their equilibrium regular order quantities:*

(*i*) *For* $\bar{\theta}^{FF} \leq c_q$: $Q_1 = Q_2 = \frac{m - c_w}{3}$.

(*ii*) *For* $\underline{\theta}^{FF} \leq c_q < \bar{\theta}^{FF}$: $Q_1 = Q_2 = \frac{m - v - 2c_w + c_q}{3}$ *for* $c_w < \frac{c_q + m - v}{2}$, *and* $Q_1 = Q_2 = 0$ *otherwise.*

(*iii*) *For* $c_q < \bar{\theta}^{FF}$: $Q_1 = Q_2 = 0$.

Appendix C: Demand Variability *v* Threshold Values for the BaseModel

Table C1 describes the threshold values in section 5 for $c_w < \min(\beta^{FS},\beta^{FF})$ and $c_w \geq \min(\beta^{FS},\beta^{FF})$, where β^{FS} and β^{FF} are given in Propositions 1 and 2 respectively.

$$x_1 = \delta - 5m + 8\sqrt{\frac{2}{7}(m^2 + 3c_w m - 3c_w^2)}$$

$$x_2 = \frac{1}{3}m + \frac{4}{3\sqrt{7}}(2c_w - m) + \delta$$

Table C1 Critical Threshold Values

Condition	Threshold values	
$c_w < \min(\beta^{FS},\beta^{FF})$	$v_M = \frac{2\sqrt{c_w(m-c_w)}}{\sqrt{5}} + \delta$ $v_2^F = \frac{2}{5}\sqrt{\frac{19}{5}}(m - c_w) + \delta$ $v_C = \left(\frac{2\sqrt{52c_w m - 41c_w^2 - 11m^2}}{5\sqrt{5}} + \delta\right)^+$	$v_1^S = \frac{2\sqrt{19}}{15}(m - c_w) + \delta$ $v_1^F = \frac{2\sqrt{2}}{5}(m - c_w) + \delta$ $v^{FS} = \frac{2\sqrt{3}}{5}(m - c_w) + \delta$
$c_w \geq \min(\beta^{FS},\beta^{FF})$	$v_M = \min(x_1,x_2)$ v_2^F is irrelevant in this case $v_C = \min(x_3,\max(\beta^{FS},\beta^{FF}))$	$v_1^S = v_1^F = v^{FS} = \min(\beta^{FS},\beta^{FF})$

$$x_3 = \frac{194m + 7\left(18(\delta - v) + \sqrt{6(57m^2 - 326m(v-\delta) + 561(v-\delta)^2)}\right)}{416}$$

Appendix D: Demand Variability v Threshold Values for the Extensions

Table D1

Endogenous wholesale price			
$\bar{v}_M = \frac{m}{\sqrt{5}} + \delta$	$\bar{v}_1^S = \frac{\sqrt{19}m}{15} + \delta$	$\bar{v}_1^F = \frac{\sqrt{2}m}{5} + \delta$	$\bar{v}_C = \frac{\sqrt{19}m}{5\sqrt{5}} + \delta$

Table D2

Alternative sequence of events

$\varepsilon_1 = \delta - c_w$

$\epsilon_2 = \frac{13m - 168c_w + 155\delta}{155}$

$\hat{v}_M^1 = \frac{7\sqrt{3c_w(1027c_w - 352m)}}{528} - \frac{71c_w}{176} + \delta$

$\hat{v}_M^2 = \frac{112\sqrt{y_1}}{25135} - \frac{49m}{457} - \frac{904c_w}{5027}$

$\hat{v}_1^S = \frac{2132c_w + 7(553 - 33\sqrt{365})m}{231\sqrt{365} - 6003)} + \delta$

$\hat{v}_2^S = \frac{(161 - 33\sqrt{14})m - 305c_w}{3(48 + 11\sqrt{14})} + \delta$

$\hat{v}_2^F = \frac{134472c_w + 7(220\sqrt{9161} - 26621)m}{51875 - 1540\sqrt{9161}} + \delta$

$\hat{v}_C^a = \frac{m - 24c_w}{47} + \frac{8\sqrt{-c_w^2 + 55mc_w - 8m^2}}{47\sqrt{5}} + \delta$

$\hat{v}_C^b = \frac{588m - 5688c_w + 77\sqrt{3496c_w^2 - 2072mc_w + 601m^2}}{8565} + \delta$

$\hat{v}_C^c = \frac{-40915m - 28920c_w + 1848\sqrt{y_2}}{365515} + \delta$

$y_1 = 363m^2 - 41844mc_w - 16607c_w^2$

$y_2 = 5(-2263m^2 + 11970mc_w - 4587c_w^2)$

$(\hat{v}_C^1, \hat{v}_C^2) = \begin{cases} (\hat{v}_C^a, \hat{v}_C^a), & \text{for } c_w \le \hat{w}_C \\ (\hat{v}_C^b, \hat{v}_C^c), & \text{otherwise} \end{cases}$, where $\hat{w}_C$ is given by the solution to $\hat{v}_C^b = \hat{v}_C^c$

Limited QR capacity

$$\tilde{v}_M = \begin{cases} \frac{2\sqrt{c_w(m-c_w)}}{\sqrt{5}} + \delta & \text{for } c_w \le \frac{2m - \sqrt{4m^2 - 45k^2}}{4}, \\ 2k + \sqrt{k^2 - \frac{4c_w(m-c_w)}{15}} + \delta & \text{for } \frac{2m-\sqrt{4m^2-45k^2}}{4} < c_w \le \tilde{w}_M, \\ \textit{irrelevant} & \text{for } \tilde{w}_M < c_w. \end{cases}$$

$$\tilde{w}_M = \frac{m - \sqrt{m^2 - 15k^2}}{2} \quad \tilde{w}_1^S = m - \frac{15k}{\sqrt{19}} \quad \tilde{w}_1^F = m - \frac{15k}{4\sqrt{2}}$$

$$\tilde{v}_1^S = \frac{2\sqrt{19}}{15}(m - c_w) + \delta \quad \tilde{v}_1^F = \frac{2\sqrt{2}}{5}(m - c_w) + \delta$$

$$\tilde{w}_C = \begin{cases} \frac{52m - 5\sqrt{36m^2 - 205(v-\delta)^2}}{82} & \text{for } \delta < v \le \frac{3k}{2} + \delta, \\ \frac{52m - 15\sqrt{4m^2 + 164k^2 - 328k(v-\delta) + 123(v-\delta)^2}}{82} & \text{for } \frac{3k}{2} + \delta < c_w \le 2k + \delta, \\ \frac{11m}{41} & \text{for } 2k + \delta < v. \end{cases}$$

Appendix E: Value of QR in Models *E*1 and *E*2

Here, we discuss the value of QR to the manufacturer, retailers, and the entire channel for the extended models *E*1 and *E*2 described in Section 6.2. Since a pure-strategy equilibrium may not exist in *FS* scenario of these extended models (see Proposition 9), in this section we only compare *FS* to *FF* scenarios for $v \leq \varepsilon_1$ and $v \geq \varepsilon_2$ in which a pure-strategy equilibrium exists in both scenarios.

The following proposition characterizes the value of QR for the manufacturer.

PROPOSITION 11. *For the models E1 and E2:*

(*i*) $\Pi_M^{SS} > \max(\Pi_M^{FS}, \Pi_M^{FF})$ *for* $v < \hat{v}_M^1$.
(*ii*) $\Pi_M^{FS} \geq \max(\Pi_M^{SS}, \Pi_M^{FF})$ *for* $\hat{v}_M^1 \leq v < \hat{v}_M^2$.
(*iii*) $\Pi_M^{FF} \geq \max(\Pi_M^{SS}, \Pi_M^{FS})$ *for If* $\hat{v}_M^2 \leq v$.
The threshold values $\hat{v}_M^1$ *and* $\hat{v}_M^2$ *are given in Appendix D.*

The next proposition characterizes retailers' value of QR. It indicates having QR ability can still be detrimental to a retailer and it can benefit its rival.

PROPOSITION 12. *For the models E1 and E2:*

(*i*) $\Pi_1^{FS} < \Pi_1^{SS}$ *if and only if* $v < \hat{v}_1^S$, *and* $\Pi_1^{FF} > \Pi_1^{SF}$.
(*ii*) $\Pi_2^{FS} > \Pi_2^{SS}$ *if and only if* $v < \hat{v}_2^S$, *and* $\Pi_2^{FF} > \Pi_2^{SF}$ *if and only if* $v < \hat{v}_2^F$.
The threshold values $\hat{v}_1^S$ *and* $\hat{v}_2^S$ *are given in Appendix D.*

In the base model, we show that QR ability can hurt a retailer regardless of its competitor's type (fast or slow). In contrast, when the regular orders are placed at the beginning of the timeline, retailers become the first mover, increasing the value extractable from QR. As a result, Proposition 12 indicates that gaining QR ability is now always beneficial to a retailer when its competitor already has QR ability. Nevertheless, QR ability can still be harmful to a retailer against a competitor who does not have QR option. In addition, gaining QR ability can still benefit a competing retailer.

The third proposition addresses the effect of QR on the channel profitability for the models *E*1 and *E*2. It shows the channel profit can still be maximized with only one fast retailer and the demand variability is the key determinant.

PROPOSITION 13. *For the models* E1 *and* E2*:*

(*i*) $\Pi_C^{FF} > \max(\Pi_C^{FS}, \Pi_C^{SS})$ *for* $\hat{v}_C^1 < v$.
(*ii*) $\Pi_C^{FS} \geq \max(\Pi_C^{FF}, \Pi_C^{SS})$ *for* $\hat{v}_C^2 < v \leq \hat{v}_C^1$.
(*iii*) $\Pi_C^{SS} \geq \max(\Pi_C^{FF}, \Pi_C^{FS})$ *for* $v \leq \hat{v}_C^2$.
The threshold values $\hat{v}_C^1, \hat{v}_C^2$ *are given in Appendix D.*

Different from our base model, Proposition 13 shows the total channel profit can also be maximized with no QR-enabled retailer at all. This result reflects the effect of the retailers' gain of first mover advantage: placing regular orders before the QR price is set. The first mover advantage encourages the excess use of QR. When demand variability is sufficiently low, there is little value to QR and it does not justify the cost for the entire channel.

Finally, we compare the retailers' profits in our base model and alternative *E*1 and *E*2 models. Let $\Pi_{i,B}^{ab}$ show retailer *i*'s equilibrium profit in the base model when retailers 1 and 2 are types *a* and *b*, where *a*,*b* = *F*,*S* and *i* = 1,2. Similarly, let $\Pi_{i,E}^{ab}$ be retailer *i*'s equilibrium profit in the alternative models. Recall that *E*1 and *E*2 models result in the same outcome.

PROPOSITION 14.

(*i*) $\Pi_{i,B}^{FF} < \Pi_{i,E}^{FF}$ *if and only if* $v < \dfrac{24c_w - 5m}{13} + \dfrac{4\sqrt{2(788c_w^2 - 376c_w m + 63m^2)}}{65}$ for i = *1*,*2*.
(*ii*) $\Pi_{1,B}^{FS} < \Pi_{1,E}^{FS}$ and $\Pi_{2,B}^{FS} > \Pi_{2,E}^{FS}$.
Note that since QR option is not used in SS scenario, our base and E1 *and* E2 *models do not differ.*

In models *E*1 and *E*2, the QR price is set after initial orders are placed. Therefore, when choosing their initial order quantity, retailers take into account the impact on the QR price whereby a larger initial order quantity results in a lower QR price. When the demand variability *v* is high, the QR option is more valuable, thus a retailer indeed orders larger initial order quantities to receive a lower QR price. However, in the FF scenario increased order quantities of both retailers results in more intense competition making the retailers worse off. In contrast, when the demand variability *v* is low, the QR option is less valuable, retailers do not have a strong incentive to order a large quantity initially, and they enjoy the first mover advantage, which makes them better off compared to the base scenario.

In the *FS* scenario, the fast retailer enjoys a higher profit in *E*1 and *E*2 models due to its first mover advantage. Thus, not surprisingly, the slow retailer is worse off in in *E*1 and *E*2 models.

Notes

[1]Chou, L., Personal interview with the president of Makalot, February 2009.
[2]Furthermore, quantity-based competition keeps the problem tractable, thus, it is commonly used in competitive models in the operations literature (e.g., Anand and Girotra 2007, Goyal and Netessine 2007, Ha et al. 2011, Mendelson and Tunca 2007).
[3]It does not matter whether the wholesale price is set first or simultaneously with QR price, because both prices are determined by the manufacturer and there is no other event happening in between these decisions.

[4]The proof of Proposition 9 in Appendix S2 shows how $c_w > \delta$ implies $c_q < c_w$.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix S1. When the Retailers Can Decide Whether to Adopt QR.

Appendix S2. Proofs.