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The impacts of quick response in a dual-channel supply chain

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Abstract. We consider the quick response (QR) in a dual-channel supply chain in which a manufacturer sells products through both its own direct channel and a retailer. With QR, the retailer has an opportunity to reorder after the random demand is realized and the manufacturer is able to reproduce after that. We characterize the equilibrium decisions for each channel and investigate the impacts of QR on the decisions and profits. Through numerical analysis, we show that QR may be beneficial to the manufacturer whereas either increases or decreases the optimal expected profit of the retailer. In addition, the supply chain is able to achieve Pareto improvement with QR under certain conditions.

Keywords: Dual-Channel Supply Chain, Quick Response, Game Theory.

1 Introduction

With the development of e-commerce, it is a growing trend for manufacturers to open up direct channels. Many papers showed that operating direct channel may increase the profits of a firm and its downstream enterprise (Arya et al. 2007, Dumrongsiri et al. 2008). Plenty of companies have established dual-channel networks, such as Apple and Huawei. In last decades, products' life cycles are increasingly shortened and some categories are eliminated from the market so quickly that it's not sensible to keep too many stocks in both direct and retail channel. The quick response originated in the US apparel industry aims to respond to the demand changes better. Iyer and Bergen (1997) evaluated the effect of reducing delivery time through QR and found that QR can increase the retailer's profit while damage the manufacturer's profit. The fast fashion retailer, Zara's practice shows that QR is a critical factor for reducing the inventory risk. Although the QR systems may increase the cost of manufacturers and retailers, it mitigates the demand uncertainty and increases the sales profits.

Retailers can postpone product ordering until the time closer to the selling season making the demand forecasts and corresponding inventory decisions match better (Fisher et al. 2001). Caro and Martínez-de-Albéniz (2010) considered the retailer competition with demand spillover and found the QR is more profitable when the demand uncertainty is higher or the cross-temporal demand correlations are bigger. Li and Ha (2008) assumed the competitive manufacturers rely on initial inventory and

QR ability to solve the problem of demand uncertainty. Lin and Par-laktürk (2010) analyzed the value of QR in supply chain with one manufacturer and two competing retailers. None of the above literature studied QR in dual-channel supply chain and our paper fills this gap. Our paper is the first to investigate QR in a dual-channel supply chain. Also, almost all literature only considers QR for sellers, whereas we study the pricing and inventory strategy assuming that QR is applied by the retailer and the manufacturer simultaneously. Furthermore, we show that the manufacturer's profit may be improved and the supply chain could achieve Pareto improvement under QR.

2 The basic model

We develop a two-stage dynamic programming model in dual-channel supply chain in which the second stage is a static game. The manufacturer sells products through its own direct channel at the direct price p_m and the retailer at the wholesale price w . The quantity reserved for the direct channel (i.e., direct inventory) is q_m . The retailer decides to order q_r units and sells to consumers at the retail price p_r . Due to demand uncertainty, both channels may be out of stock during the selling season. In that case, QR allows the manufacturer to start a possible QR production with a quantity of q'_m (i.e., QR inventory) and the retailer to place a possible QR order with a quantity of q'_r . The unit early and QR production cost of the manufacturer is c and c_{qr} , where $c_{qr} > c$. For a unit QR order, the retailer is charged by $w+e$, where e is the QR order fee, indicating that the retailer pays more for the QR order than the initial order. After the selling season, unsold products are disposed by a unit salvage value s . As is shown in Fig. 1, the sequence of the events is as follows:

- (i) In the first stage, the manufacturer decides the wholesale price w ;
- (ii) In the second stage, the manufacturer jointly decides the direct price p_m and the direct inventory q_m , and meanwhile the retailer jointly decides the retail price p_r and initial order quantity q_r .

All decisions above were decided before the selling season. We will use the notations listed in Table A-1 in the Appendix to define our problem.

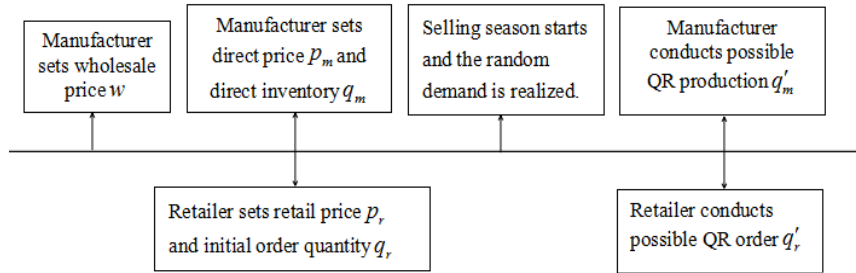


Fig. 1. The sequence of the events in the QR model.

Similar to Li et al. (2016), the demand function of the direct and retail channel is given by $d_m = (1-\theta)(a+\varepsilon) - rp_m + tp_r$ and $d_r = \theta(a+\varepsilon) - rp_r + tp_m$. θ is the retailer's market share. The demand includes the certain part a and the random part ε which distributes on $U[-b, b]$ where $0 \leq b < a$. According to Li, Zhang and Yan (2012), the demand of many products, e.g., agricultural seeds and festival souvenirs, conforms to the uniform distribution if the life cycle is short and the demand intervals can be inferred from the past data. To provide an transformation of the inventory decisions, we define z_m , z_r and z_{mr} as inventory factors representing the product quantity ordered to satisfy the stochastic portion of the demand, where $q_m = (1-\theta)(a+z_m) - rp_m + tp_r$, $q_r = \theta(a+z_r) - rp_r + tp_m$ and $q_m + q_r = a + z_{mr} - (r-t)(p_m + p_r)$.

We assume the scenario where the retailer is out of stock before the manufacturer as RO, whereas the scenario where the manufacturer is out of stock before the retailer as MO. Whether stock-out occurs in the retailer or the manufacturer, it will be meet completely in both direct and retail channels through QR. In RO, if $z_r < \varepsilon \leq z_{mr}$, the retailer places QR order with a quantity of q'_r where $q'_r = \theta(\varepsilon - z_r)$ and the manufacturer does not start QR production. For $\varepsilon > z_{mr}$, QR is conducted on both channels where $q'_m = \varepsilon - z_{mr}$, $q'_r = \theta(\varepsilon - z_r)$ and for $\varepsilon \leq z_r$, neither channel will conduct QR. In MO, if $z_m < \varepsilon \leq z_r$, the manufacturer conducts QR production with a quantity of q'_m where $q'_m = (1-\theta)(\varepsilon - z_m)$ while the retailer does not place QR order. QR is conducted on both channels if $\varepsilon > z_r$, and is not conducted by either channel if $\varepsilon \leq z_m$.

According to the above, the manufacturer's expected profit in RO is:

$$\begin{aligned} \pi_m^{qr} = & p_m E(d_m) + wq_r + (w+e)q'_r - c(q_m + q_r) - c_{qr}q'_m + sE(q_m - d_m)^+ \\ & + s \int_{z_r}^{\theta z_r + (1-\theta)z_m} (\theta z_r + (1-\theta)z_m - \varepsilon) f(\varepsilon) d\varepsilon \end{aligned} \quad (1)$$

where $E(\cdot)$ is the expectation operator and $x^+ = \max(x, 0)$. The manufacturer's expected profit in MO is:

$$\pi_m^{qr} = p_m E(d_m) + wq_r + (w+e)q'_r - c(q_m + q_r) - c_{qr}q'_m + sE(q_m - d_m)^+ \quad (2)$$

The retailer's expected profit is the same in both scenarios which is:

$$\pi_r^{qr} = p_r E(d_r) - wq_r - (w+e)q'_r + sE(q_r - d_r)^+ \quad (3)$$

Note that we use the superscript 'qr' to represent the scenario with QR throughout this paper. By using backward induction, we can obtain the global optimum solutions in Propositions 1-2. Proofs of all propositions are given in the Appendix.

Proposition 1. With QR, given a wholesale price w of the first stage, the optimal direct price $p_m^{qr*}(w)$, direct inventory $q_m^{qr*}(w)$, retail price $p_r^{qr*}(w)$ and initial order quantity $q_r^{qr*}(w)$ are given by:

a) If $w \geq w_E$, $p_m^{qr*}(w) = \bar{p}_m^{qr*}(w)$, $q_m^{qr*}(w) = \bar{q}_m^{qr*}(w) = (1-\theta)(a + \bar{z}_m^{qr*}(w)) - r\bar{p}_m^{qr*}(w) + t\bar{p}_r^{qr*}(w)$,
 $p_r^{qr*}(w) = \bar{p}_r^{qr*}(w)$, $q_r^{qr*}(w) = \bar{q}_r^{qr*}(w)$;

b) If $w < w_E$, $p_m^{qr*}(w) = \tilde{p}_m^{qr*}(w)$, $q_m^{qr*}(w) = \tilde{q}_m^{qr*}(w) = (1-\theta)(a + \tilde{z}_m^{qr*}(w)) - r\tilde{p}_m^{qr*}(w) + t\tilde{p}_r^{qr*}(w)$,
 $p_r^{qr*}(w) = \tilde{p}_r^{qr*}(w)$, $q_r^{qr*}(w) = \tilde{q}_r^{qr*}(w)$;

where $w_E = \frac{c-s}{c_{qr}-c}e + s$, $\bar{p}_m^{qr*}(w) = \tilde{p}_m^{qr*}(w) = \frac{[2(1-\theta)r + \theta t]a + 3rtw + 2r(r-t)c}{4r^2 - t^2}$,

$\bar{p}_r^{qr*}(w) = \tilde{p}_r^{qr*}(w) = \frac{[2\theta r + (1-\theta)t]a + (2r^2 + t^2)w + t(r-t)c}{4r^2 - t^2}$,

$\bar{q}_r^{qr*}(w) = \tilde{q}_r^{qr*}(w) = \theta(a + \bar{z}_r^{qr*}(w)) - r\bar{p}_r^{qr*}(w) + t\bar{p}_m^{qr*}(w)$, $\bar{z}_m^{qr*}(w) = \frac{2b}{1-\theta}(\frac{c_{qr}-c}{c_{qr}-s} - \frac{\theta e}{w+e-s}) - b$,

$\bar{z}_r^{qr*}(w) = \tilde{z}_r^{qr*}(w) = \frac{2be}{w+e-s} - b$ and $\tilde{z}_m^{qr*} = 2b\frac{c_{qr}-c}{c_{qr}-s} - b$.

Considering the optimal responses to the wholesale price, we obtain the optimal wholesale price for the manufacturer in the following proposition.

Proposition 2. With QR, the optimal wholesale price w^{qr*} is given by:

- For $\bar{w}^{qr} \geq w_E$, the manufacturer sets $w^{qr*} = \bar{w}^{qr}$;
- For $\bar{w}^{qr} < w_E < \tilde{w}^{qr}$, the manufacturer sets $w^{qr*} = w_E$;
- For $\tilde{w}^{qr} \leq w_E$, the manufacturer sets $w^{qr*} = \tilde{w}^{qr}$, where

\bar{w}^{qr} and \tilde{w}^{qr} satisfy $\theta a - rp_r^{qr*} + t\bar{p}_m^{qr*} + \frac{\theta(z_r^{qr*} + b)^2}{4b} + \frac{2r^2 + t^2}{4r^2 - t^2}[t(\bar{p}_m^{qr*} - c) - r(\bar{w}^{qr} - c)] = 0$ and

$\theta a - rp_r^{qr*} + t\tilde{p}_m^{qr*} + \frac{\theta(z_r^{qr*} + b)^2}{4b} + [t(\tilde{p}_m^{qr*} - c) - r(\tilde{w}^{qr} - c)]\frac{2r^2 + t^2}{4r^2 - t^2} - \frac{2b\theta e(c_{qr} - c - e - \frac{c_{qr} - s}{\tilde{w}^{qr} + e - s})}{(\tilde{w}^{qr} + e - s)^2} = 0$.

The manufacturer and the retailer have the same relative shortage costs when the value of wholesale price is w_E . If $\bar{w}^{qr} > w_E$, the retailer's relative shortage cost is smaller than that of the manufacturer. Thus, the retailer will be easier to be out of stock than the manufacturer and the equilibrium occurs in RO. Similarly, if $\tilde{w}^{qr} < w_E$, the manufacturer's relative shortage cost is smaller than that of the retailer which results in a lower direct inventory so that the equilibrium occurs in MO.

Next, we consider the benchmark model with no QR. The sequence of events is the same as that in QR model except for not requiring the last stage. Similarly, we solve it by using backward induction. The manufacturer's expected profit is:

$$\pi_m = p_m E[\min(q_m, d_m)] + wq_r - c(q_m + q_r) + sE(q_m - d_m)^+ \quad (4)$$

The retailer's expected profit is:

$$\pi_r = p_r E[\min(q_r, d_r)] - wq_r + sE(q_r - d_r)^+ \quad (5)$$

Proposition 3. Assume $(1-\theta)(a-b)-rc > 0$ and $\theta(a-b)-rw > 0$, we have

- a) For a given wholesale price w , the optimal direct price, retail price, direct inventory and initial order quantity are given below:

$$p_m^*(w) = \frac{[2(1-\theta)r + \theta t]a + 3rtw + 2r(r-t)c}{4r^2 - t^2} - \frac{2r(1-\theta)(z_m^*(w) - b)^2 + \theta t(z_r^*(w) - b)^2}{4b(4r^2 - t^2)},$$

$$p_r^*(w) = \frac{[2\theta r + (1-\theta)t]a + (2r^2 + t^2)w + (r-t)tc}{4r^2 - t^2} - \frac{(1-\theta)t(z_m^*(w) - b)^2 + 2\theta r(z_r^*(w) - b)^2}{4b(4r^2 - t^2)},$$

$$q_m^*(w) = (1-\theta)(a + z_m^*(w) - rp_m^*(w) + tp_r^*(w)), \quad q_r^*(w) = \theta(a + z_r^*(w) - rp_r^*(w) + tp_m^*(w)),$$

where $z_m^*(w) = 2b \frac{p_m^*(w) - c}{p_m^*(w) - s} - b$ and $z_r^*(w) = 2b \frac{p_r^*(w) - w}{p_r^*(w) - s} - b$;

- b) The optimal wholesale price satisfies the following first-order condition:

$$\theta(a + z_r^*) - rp_r^* + tp_m^* + [t(p_m^* - c) - r(w^* - c)]A(w^*) + \theta(w^* - c) \frac{2bA(w^*)(w^* - s) - b(p_r^* - s)}{(p_r^* - s)^2} = 0,$$

$$A(w^*) = \frac{(2r^2 + t^2 - 2\theta r \frac{2b(w^* - s)}{(p_r^* - s)^2})(4r^2 - t^2 - 2(1-\theta)r \frac{2b(c-s)^2}{(p_m^* - s)^3}) + (1-\theta)t \frac{2b(c-s)^2}{(p_m^* - s)^3} (3rt - \theta t \frac{2b(w^* - s)}{(p_r^* - s)^2})}{(4r^2 - t^2 - 2\theta r \frac{2b(w^* - s)}{(p_r^* - s)^2})(4r^2 - t^2 - 2(1-\theta)r \frac{2b(c-s)^2}{(p_m^* - s)^3}) - (1-\theta)t \frac{2b(c-s)^2}{(p_m^* - s)^3} \theta t \frac{2b(w^* - s)}{(p_r^* - s)^2}}.$$

3 The impacts of quick response

In this section, we study the impacts of QR in the dual-channel supply chain by numerical examples. The default values of all parameters are given by $a=2000$, $b=500$, $r=50$, $t=40$, $s=0.2$, $c=1$, $c_{qr}=1.5$ and $e=0.5$. Firstly, we explore the effects of QR on the optimal decisions and profits of the manufacturer and the retailer for different retailer's market share θ in Figs. 2-4.

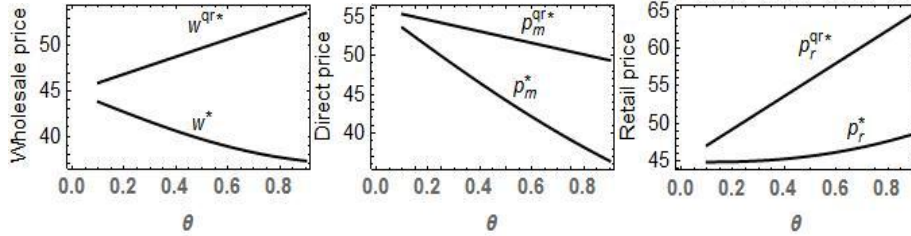


Fig. 2. The impact of QR on the optimal wholesale price, direct price and retail price.

We can obtain some interesting observations from Fig. 2. We find that the optimal wholesale price in QR model is substantially larger than that in no QR model. For the manufacturer, providing QR policy to the retailer brings higher production cost gives the reason to propose higher wholesale price. Naturally, the optimal selling prices of both channels are higher with QR. The optimal retail price increases in the retailer's market share because the optimal wholesale price increases in it. The optimal direct price decreases as the retailer's market share increases since the effect of its reduced market share outweighs that of the increased wholesale price.

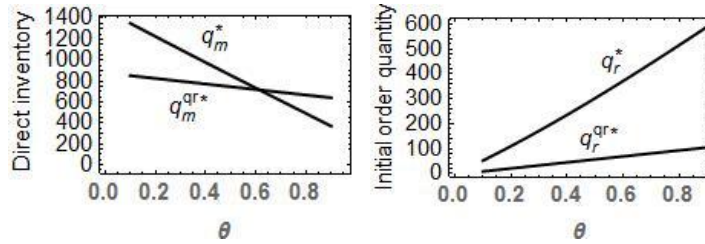


Fig. 3. The impact of QR on the optimal direct inventory and initial order quantity.

For the manufacturer, QR production allows him to decrease the direct inventory while the retailer's QR order prompts to increase it. From Fig. 3, we find that with QR, the manufacturer's optimal direct inventory is lower than that with no QR when the retailer's market share is low because the effect of QR production exceeds that of the QR order. However, if θ is sufficiently big, the effect of QR order exceeds that of QR production and the optimal direct inventory is higher than that with no QR. For the retailer, the higher optimal wholesale price and retail price results in lower initial order quantity. Therefore, the retailer's initial order quantity will be greatly reduced in contrast to that without QR.

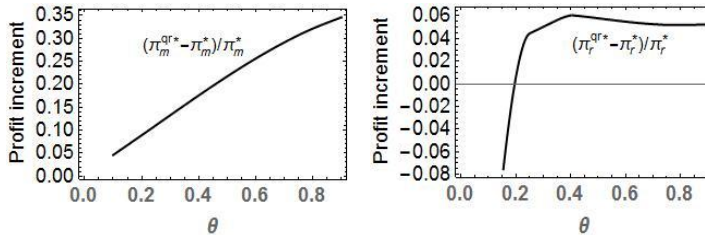


Fig. 4. The impact of QR on the increment of the optimal expected profit of the manufacturer and the retailer.

Form Fig. 4, we find that QR is beneficial to the manufacturer. This is because QR increases the expected sales revenue of both direct and retail channel. Although the manufacturer's production cost increases, it is less than the increase in sales revenue. Moreover, the manufacturer's expected profit increment increases in the retailer's market share. For the retailer, the expected profit might increase or decrease. When the retailer's market share is low, QR hurts the retailer, for the reason that the sales

revenue increment is less than the procurement cost increment incurred by the QR. As the market share increases, the outcome is reversed and the retailer will benefit from QR. It's interesting to find that there exists Pareto improvement by QR when the market share of the retailer is sufficiently high. That is, QR is easier to implement in this case than other situations because both the manufacturer and the retailer will benefit from QR so that accept it.

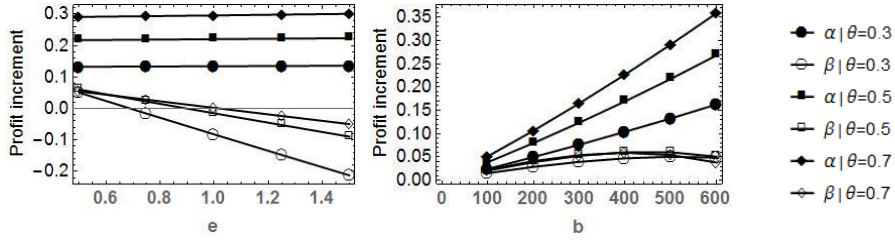


Fig. 5. The impacts of e and b on the increment of the optimal expected profits of the manufacturer and the retailer, where $\alpha = (\pi_m^{qr*} - \pi_m^*) / \pi_m^*$, $\beta = (\pi_r^{qr*} - \pi_r^*) / \pi_r^*$.

From Fig. 5, we show that the manufacturer's optimal expected profit increment with QR increases in the QR order fee, while that of the retailer decreases in it. When the value of e is small, the retailer benefits from QR. Once the QR order fee exceeds a threshold, the retailer's performance turns worse. We also show that the threshold will increase in the retailer's market share. This is because the retailer's expected sales revenue of QR order increases in its market share. Thus, QR achieves Pareto improvement with a sufficiently small QR order fee. This implies that QR may not be successful when it is hard to executive, e.g., the QR order fee is high. The manufacturer should reduce QR order fee as much as possible to prompt QR.

We find that the manufacturer's optimal expected profit increment increases in the random demand fluctuation range, while that of the retailer first increases in it and then decreases in it. We can explain it as follows: if the random demand is small, the impact from the retailer's increased sales income of QR order decreases; otherwise, the impact from the increased procurement cost increases. Therefore, if the market demand fluctuates too much, it is better for the retailer not to accept QR because the manufacturer may set a high wholesale price.

4 Conclusions

The literature on quick response has widely focused on tradition retail channel supply chain and firms' competition while we investigate the value of quick response in a dual-channel supply chain consisting of a manufacturer and a retailer. In this paper, we give the equilibrium decisions and profits of both channels. Our numerical results demonstrate that with QR strategy, the manufacturer could set a higher wholesale and direct price. The retailer reduces the initial order quantity significantly and set a higher retail price. For the manufacturer, direct inventory may not necessarily be reduced

because of the retailer's QR order. We show that the manufacturer may be benefits from quick response because QR makes the manufacturer's sales revenue of direct and retail channel increase substantially. However, the retailer's expected profit will either be increased or decreased because the retailer has increased sales revenue and procurement cost as well. Finally, we find that QR could achieve Pareto improvement if the retailer's market share is high, the QR order fee is low, or the random demand fluctuation range is either not too big or too small. In the future, considering an endogenous QR wholesale price is a valuable research issue. It would also be interesting to study how strategic consumer behavior influences the value of quick response in a dual-channel supply chain.

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