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Price competition model in centralized and decentralized supply chains with demand disruption

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Abstract: The paper studies the price competition of a supply chain with one supplier and tow competing retailers under occasional demand disruption. The demand disruption for two retailers occurs with different probability. The optimal prices of the supplier and two retailers in centralized or decentralized pattern are obtained under demand disruption. We find that the profits of chain partners are decreasing with the occurrence probability of the demand disruption.

Keywords: Coordination, Occurred probability, Supply chain profit

1. Introduction

The market demand is often disrupted by some haphazard events, such as the promotion of sale, the raw material shortage, the new tax or tariff policy, machine breakdown, and so on. All the retailers and suppliers in the entire supply chain will be severely affected by these demand disruptions.

A large amount of research has been conducted on supply chain disruption management. Zhang et al. (2004) advocated the establishment of a supply chain exception management system for rapid detection of exceptional events in the supply chain system, collaborative management, and achieving rapid response to improve the competitiveness. Debra et al. (2005) discussed how to respond to the emergency in or out supply chain. Yossi (2001) pointed that the emergency management of the supply chain was concerned by the academia after the 911.Qi et al. (2004) researched a one-supplier-one-retailer supply chain coordination problem with demand disruption. Xu et al. (2005) made a similar model with production cost disruption and extended the results to multiple independent retailers. Xiao et al. (2005) considered the coordination of the supply chain with demand disruption and researched a price-subsidy rate contract to make the competing retailers identical in the investing. Lee et al. (2003) studied the impact of the logistics scheduling leaded by the emergencies. Qi et al. (2004) researched how to coordinate the supply chain with one supplier and one retailer after the demand disruption to make the supply chain profit maximum.

In this paper, we will consider the demand disruption of a supply chain with a single supplier and two retailers who compete in the market. Our particular interest is the probability of the demand disruption's occurrence for two retailers respectively. We explore the profit changes by the price competition between two retailers under demand disruption.

2. Basic model

We consider a supply chain consisting of one supplier and two competing retailers, they only sell one product. Only one supply chain is consisted by them. We will focus on the case of a disruption to demand.

We have the following notations ($i = 1, 2$):

w_0: The unit wholesale price of supplier;

p_i: The retail price of retailer i;

q_i: The market demand for retailer i;

φ_i: The probability of the emergencies of the supply chain i;

π_i: The profit of retailer i;

π_g: The profit of supplier;

Π: The total profit of the supply chain;

We assume that the demand function of retailer i is:

$$q_i(p_i, p_j) = a_i - p_i + d_i p_j, \quad i, j = 1,2, \quad j \neq i \tag{1}$$

Where the a_i is the market scale for retailer i; d_i is the substitutability coefficient of the two retailers.

We assumed that the probability of disruptions in the supply chain i is φ_i. When the disruptions occur, the market scale or the demand for retailer i will change, and the demand function of retailer i is:

$$q_i^{'} = a_i^{'} - p_i + d_i^{'} p_j \tag{2}$$

Where $a^{'}_i$ is the market scale for retailer i after disruption, the $d_i^{'}$ is the substitutability coefficient of the two retailers under disruption. Assume that the new disrupted market scale $a^{'}_i$ is given by $a_i^{'} = a_i + \Delta a_i$, and the new disrupted substitutability coefficient $d_i^{'}$ is given by $d_i^{'} = d_i + \Delta d_i$.

So the profit of supplier is:

$$\begin{aligned}\pi_g &= w_0(a_1^{'} - p_1 + d_1^{'} p_2)\varphi_1 + w_0(a_1 - p_1 + d_1 p_2)(1-\varphi_1) \\ &\quad + w_0(a_2^{'} - p_2 + d_2^{'} p_1)\varphi_2 + w_0(a_2 - p_2 + d_2 p_1)(1-\varphi_2) \\ &= w_0(\Delta a_1\varphi_1 + \Delta d_1\varphi_1 p_2 + a_1 - p_1 + d_1 p_2 + \Delta a_2\varphi_2 + \Delta d_2\varphi_2 p_1 + a_2 - p_2 + d_2 p_1) \\ &= w_0(\beta_1 + \beta_2 + \lambda_1 p_2 + \lambda_2 p_1 - p_1 - p_2)\end{aligned} \tag{3}$$

where

$$\Delta a_1\varphi_1 + a_1 = \beta_1, \Delta a_2\varphi_2 + a_2 = \beta_2, \Delta d_1\varphi_1 + d_1 = \lambda_1, \Delta d_2\varphi_2 + d_2 = \lambda_2 \tag{4}$$

We can obtain the profits of the two retailers respectively.

$$\begin{aligned}\pi_1 &= (p_1 - w_0)(a_1^{'} - p_1 + d_1^{'} p_2)\varphi_1 + (p_1 - w_0)(a_1 - p_1 + d_1 p_2)(1-\varphi_1) \\ &= (p_1 - w_0)(\beta_1 + \lambda_1 p_2 - p_1)\end{aligned} \tag{5}$$

$$\begin{aligned}\pi_2 &= (p_2 - w_0)(a_2^{'} - p_2 + d_2^{'} p_1)\varphi_2 + (p_2 - w_0)(a_2 - p_2 + d_2 p_1)(1-\varphi_2) \\ &= (p_2 - w_0)(\beta_2 + \lambda_2 p_1 - p_2)\end{aligned} \tag{6}$$

3. Demand disruptions with different supply chain structures

3.1. Demand disruptions with decentralized supply chains

We consider a supply chain consisting of one supplier and two competing retailers. For a decentralized supply chain (DSC), the supplier produces goods with the unit production cost and sells the product through the retailers. After purchasing the product from the supplier with the unit wholesale price, retailers add some values to the product with the unit selling cost, and then determine his retail price to sell the product. We assume that the costs above are normalized to zero.

Differentiating Eqs (5) and (6), we have the optimal retail price of retailers for any given wholesale price:

$$p_1^{'} = \frac{\eta_1 + (\lambda_1 + 2)w_0}{4 - \lambda_1\lambda_2}, \ p_2^{'} = \frac{\eta_2 + (\lambda_2 + 2)w_0}{4 - \lambda_1\lambda_2} \tag{7}$$

where

$$\eta_1 = \lambda_1\beta_2 + 2\beta_1, \eta_2 = \lambda_2\beta_1 + 2\beta_2$$

Inserting Eq. (7) into Eq. (3) and for the first order conditions, we have the optimal wholesale price of the supplier.

$$w_0^* = \frac{\eta}{2(2\gamma - 4 - \lambda)} \tag{8}$$

where

$$\gamma = 4 - \lambda_1\lambda_2, \eta = \eta_1 + \eta_2$$

With the optimal wholesale prices, we can obtain the optimal retail price of retailers.

$$p_1^{*'} = \frac{\eta_1}{\gamma} + (\lambda_1 + 2)\frac{\eta}{2(2\gamma - 4 - \lambda)\gamma}, \ p_2^{*'} = \frac{\eta_2}{\gamma} + (\lambda_2 + 2)\frac{\eta}{2(2\gamma - 4 - \lambda)\gamma} \tag{9}$$

3.2. Demand disruption in a centralized supply chain

For a centralized supply chain (CSC), the supplier produces the product and sells it at a certain price. Thus the total profit of supply chain is:

$$\Pi = \pi_g + \pi_1 + \pi_2 = p_1(\beta_1 + \lambda_1 p_2 - p_1) + p_2(\beta_2 + \lambda_2 p_1 - p_2) \qquad (10)$$

Differentiating this and we have the optimal retail prices under disruption:

$$p_1^* = \frac{2\beta_1 + \lambda\beta_2}{4-\lambda^2}, p_2^* = \frac{2\beta_2 + \lambda\beta_1}{4-\lambda^2}, \lambda = \lambda_1 + \lambda_2 \qquad (11)$$

With the optimal prices, we can obtain the demand for products and the profit of the supply chain:

$$q_1^* = \frac{2\beta_1 + (\lambda_1 - \lambda_2)\beta_2 - \lambda\lambda_2\beta_1}{4-\lambda^2}, q_2^* = \frac{2\beta_2 + (\lambda_2 - \lambda_1)\beta_1 - \lambda\lambda_1\beta_2}{4-\lambda^2} \qquad (12)$$

$$\Pi^* = \frac{\beta_1^2 + \beta_2^2 + \lambda\beta_1\beta_2}{4-\lambda^2} \qquad (13)$$

4. Numerical examples

The disruptions affect the optimal decisions and the profitability of the supply chain to a certain extent. We explore the effects of the demand disruptions using the following numerical examples. Assume the following values of parameters:

$a_1 = a_2 = 20, d_1 = 0.5, d_2 = 0.4, \Delta a_1 = -3, \Delta d_1 = 0.05$.

Fig. 1 illustrates how the optimal wholesale price of the supplier in decentralized supply chain. And the optimal retail price of two retailers in centralized or decentralized supply chain depends on occurrence probability of demand disruption. We assume that φ_1 changes from 0 to 1 and φ_2=0.1.

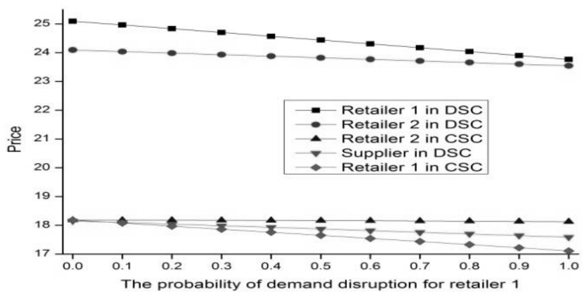

Fig. 1: The optimal price of supply chain partners versus the probability of demand disruption for retailer 1

From Fig. 1, we can see that the optimal wholesale price of the supplier and the two retailers in DSC are decreasing with the occurrence probability of demand disruption for retailer 2.And the optimal retail price of the two retailers in CSC has the same trend. Because the demand for retailer 1 drops, he would like to lower the retail price to sell more goods. For market competition, retailer 2 will also bring the retail price down. And the supplier will lower his wholesale prices and share the demand disruption.

Fig. 2 describes how the optimal retail prices of retailers in DSC depend on occurrence probability of demand disruption. We assume that φ_1=0.1 and φ_2 changes from 0 to 1.

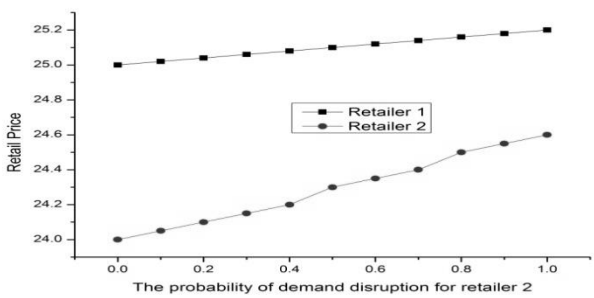

Fig. 2: The optimal retail price of retailers in DSC versus the probability of demand disruption for retailer 2

From Fig. 2, we can find that the optimal retail price of two retailers in DSC is increasing with the occurrence probability of demand disruption for retailer 2. The result in Fig. 2 is different from the one in Fig. 1.

Fig. 3 illustrates how the profits of members of supply chains or supply chain itself depend on the probability of demand disruption for retailer 1. We assume that φ_1 changes from 0 to 1 and $\varphi_2 = 0.1$.

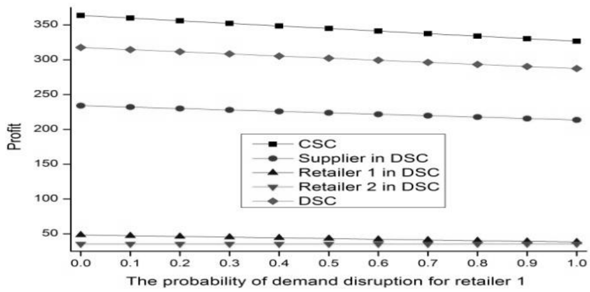

Fig. 3: The profit versus the probability of demand disruption for retailer 1

From Fig. 3, we can see that the profit of CSC, members in CSC and DSC are decreasing with the probability of demand disruption for retailer 1. The demand disruption reduces the profits of supply chain partners.

5. Conclusion

In this paper, we study the price competition of a supply chain with one supplier and two competing retailers under occasional demand disruption. We mainly focus on the price competition of the two retailers when the demands for them are disrupted with different probability. The optimal retail prices for the two retailers in the centralized and decentralized supply chains are obtained. We found that the profits of chain partners are decreasing with the occurrence probability of demand disruption.

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