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Price competition of supply chains under demand uncertainty

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Abstract: We study the price competition of two supply chains with demand uncertainty. Each supply chain consists of one risk-averse manufacturer and one risk-averse retailer. We consider two cases: two competing decentralized supply chains and two competing integrated supply chains. We analyze the effects of the demand uncertainty on the supply chains' expected profits. In the first case, we find that the expected profit of one supply chain is first increasing and then decreasing with the demand uncertainty of him, otherwise decreasing with the demand uncertainty of his rival. In the other case, we show that the more uncertain the demand of one supply chain, the lower expected profit of him and the rival's will be.

Keywords: Price competition, Demand uncertainty, Supply chain management

1. Introduction

Pricing is important business behavior and competing firms or supply chains often play a price war to attract customers. The price competition is a main form of the market competitions. Thus, the price competition of supply chains has become a hot topic in recent years.

In the literature on price competition with supply chains, most assumed deterministic demand. Xiao (2010) discussed two competing supply chains, each consisting of one supplier and one manufacturer. He analyzed supply chain member's price policy in three competition scenarios, then compared the price and scale of market in different scenario, and concluded that first two scenarios exist stable equilibriums. Albert (2008) investigated contracting and information sharing in two competing supply chains, each consisting of one manufacturer and one retailer. The two supply chains are identical, except they may have different investment costs for information sharing. Lu (2009) considered a market with two competing supply chains with common customers, each consisting of one manufacture and one retailer. He assumed that supply chain competing on two sides' product's qualities and prices. Edward (2010) considered price competition with a linear demand function and compared two cases. He explored the effect of varying the level of price competition on the profits of the industry participants. Ai (2007) presented new competing channel structure models under bargaining power, and also presented equilibrium result and area. Liao (2009) proposed the structure models of chain to chain competition comprised of two manufacturers and two exclusive retailers and disclosed the impact of price competition and service competition and cost of service on the vertical structure performance.

Some researchers studied demand uncertainty in the price competition of supply chains. Tiao (2008) developed a price-service competition model of two supply chains to investigate the optimal decisions of players under demand uncertainty. Fernando (2005) investigated the equilibrium behavior of decentralized supply chains with competing retailers under demand uncertainty. Fernando (2007) addressed a general model for two-echelon supply chains with N competing retailers served by a common supplier. Each retailer's stochastic demand function depends on his own retail price, as well as those of all of his competitors, but also on the service levels guaranteed by the N firms. Ibtinen (2010) studied a buyback contract model of the competitive newsvendor problem between a single supplier and multiple retailers under simultaneous price and safety stock competition. Yi (2010) constructed a Closed-loop Supply Chain which was composed of one manufacturer and two retailers with product remanufacturing under uncertain demand. Hou (2010) investigated equilibrium and coordination of system in a two-echelon supply chain with one supplier and many price-competing retailers under stochastic demand. Ai (2008) investigated the impact of market risk on the performance of control structure under chain to chain competition and developed a series models to examine the impact of market risk and competition intensity on the performance of each party with the tool of Bayesian and game theory. Ai (2010) proposed chain to chain price competition models defined by two manufacturers and two exclusive retailers under demand uncertainty.

To the best of our knowledge, few works consider players' risk due to demand uncertainty (Jiang, 2009) under the price competition of two independent supply chains. In this paper, the competition of two independent chains to address the above issues is proposed, where each supply chain consists of one risk-averse manufacturer and one risk-averse retailer. The two retailers compete in retail price whereas two manufacturers compete in wholesale price in a demand uncertainty environment. The relations among supply chain structures, expected profits, and demand uncertainty are examined. Two supply chain structures: both chains are integrated and both chains are decentralized, are discussed. Our paper is closely related to Xiao and Yang (2008) for the effects of risk sensitivity on retailers' decisions under demand uncertainty. But they did not consider the manufacturer's risk sensitivity and did not concern the supply chains' structures, which are mainly studied in our model.

The remainder of this paper is organized as follows. The next section describes the model and introduces the notations. Section 3 studies the influence of supply chain structure on the equilibrium solution. In section 4, a simple numeral example is given to investigate the impact of demand uncertainty on the expected profits of players and supply chains. Finally we conclude in Section 5.

2. The Model

We assumed that there are two competing supply chains that offer the same product in the demand uncertainty market. The supply chains are either integrated, i.e. manufacturers sell their own product, or they are decentralized where manufacturers sell their products to the market through retailers. Each chain consists of one risk adverse manufacturer and one risk adverse retailer. The retailers engage in the price competition.

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

α_i: The stochastic market base for retailer i, with $E(\alpha_i) = \mu_i$, $D(\alpha_i) = {\sigma_i}^2$;

β: The demand sensitivity of one retailer to his own retail price;

γ: The demand sensitivity of one retailer to his rival's retail price, $\beta > \gamma > 0$;

p_i: The retail price of retailer i;

w_i: The unit wholesale price of manufacturer i;

λ_i: The risk sensitivity of manufacturer i ($\lambda_i > 0$);

η_i: The risk sensitivity of retailer i ($\eta_i > 0$);

We will assume that the demand for product i as a function of the retail prices p_i is given by Equ. (1).

$$d_i = \alpha_i - \beta p_i + \gamma p_j, i, j \in \{1, 2\}, i \neq j \qquad (1)$$

This demand function is widely used in price competition of supply chains researches (Edward and Yong, 2010). The retailer with large μ_i has a relative advantage of accessing customer due to a better brand, quality, service, and so on. The market demand of each retailer is an increasing function of his rival's retail price, but a decreasing function of his own retail price. We assume that the manufacturers have identical marginal production costs while the retailers have identical marginal operating costs, and these costs are normalized to zero (Albert and Shi, 2008). This paper also assumes that two manufacturers act as Stackelberg leaders in both integrated supply chains and decentralized supply chains.

3. Two Competing Supply Chains

In this section we will discuss the equilibrium solutions for integrated supply chains and decentralized supply chains separately. We will also discuss the effects of the demand uncertainty on the supply chains' expected profits in the following section. Considering the profits of supply chains are stochastic variable, we assess their expected utilities via the Mean-Variance value function of their random profit.

3.1. Two Competing Decentralized Supply Chains

In a decentralized supply chain, manufacturer i sells the product to his exclusive retailer i at wholesale price w_i given the wholesale price, the retailer then decides a retail price which maximizes its profits. The manufacturer can predict the retailers' pricing decisions for any given wholesale price and thus can optimize its own profits.

The profit of retailer i is

$$\pi_{Ri}^{DD} = (p_i - w_i)(\alpha_i - \beta p_i + \gamma p_j) \qquad (2)$$

Thus, the Mean-Variance value function of his profit is

$$u_i(\pi_{Ri}^{DD}) = E(\pi_{Ri}^{DD}) - \eta_i D(\pi_{Ri}^{DD})$$
$$= (p_i - w_i)(\mu_i - \beta p_i + \gamma p_j) - \eta_i (p_i - w_i)^2 {\sigma_i}^2 \quad (3)$$

For the first order conditions, we have

$$\frac{\partial u_i(\pi_{Ri}^{DD})}{\partial p_i} =$$
$$\mu_i - 2(\eta_i {\sigma_i}^2 + \beta)p_i + \gamma p_j + (\beta + 2\eta_i {\sigma_i}^2)w_i = 0 \quad (4)$$

Notice that

$$\frac{\partial^2 u_i(\pi_{Ri}^{DD})}{\partial {p_i}^2} = -2(\eta_i {\sigma_i}^2 + \beta) < 0 \qquad (5)$$

So it follows that the optimal retail price of retailer i for any given wholesale price is

$$p_i = M(A_i w_i + B_j w_j + C_i) \qquad (6)$$

Where $A_i = 4\eta_i \eta_j {\sigma_i}^2 {\sigma_j}^2 + 2\beta \eta_j {\sigma_j}^2 + 4\beta \eta_i {\sigma_i}^2 + 2\beta^2$, $C_i = 2\mu_i \eta_j {\sigma_j}^2 + 2\beta\mu_i + \mu_j \gamma$, $B_j = 2\gamma\eta_j {\sigma_j}^2 + \beta\gamma$, and $M = 1/[4\eta_i \eta_j {\sigma_i}^2 {\sigma_j}^2 + 4\beta(\eta_i {\sigma_i}^2 + \eta_j {\sigma_j}^2) + 4\beta^2 - \gamma^2]$.

The profit of manufacturer i is

$$\pi_{Mi}^{DD} = w_i(\alpha_i - \beta p_i + \gamma p_j) \qquad (7)$$

Thus, the Mean-Variance value function of his profit is

$$u_i(\pi_{Mi}^{DD}) = E(\pi_{Mi}^{DD}) - \lambda_i D(\pi_{Mi}^{DD})$$
$$= w_i(\mu_i - \beta p_i + \gamma p_j) - \lambda_i {w_i}^2 {\sigma_i}^2 \qquad (8)$$

Inserting Eq. (6) into Eq. (8), and for the first order conditions, we have

$$\frac{\partial u_i(\pi_{Mi}^{DD})}{\partial w_i}$$
$$= \mu_i + M(\gamma C_j - \beta C_i) + M(\gamma A_j - \beta B_j)w_j$$
$$+2(\gamma M B_i - \beta M A_i - \lambda_i {\sigma_i}^2)w_i = 0 \qquad (9)$$

Notice that

$$\frac{\partial^2 u_i(\pi_{Mi}^{DD})}{\partial {w_i}^2} = M(\gamma B_j - \beta A_j) - \lambda_j {\sigma_j}^2 \qquad (10)$$

Thus, we assume $M(\gamma B_j - \beta A_j) < \lambda_j {\sigma_j}^2$ throughout this paper. So it follows that the optimal wholesale price of manufacturer i is

$$w_i^* = \frac{E_j D_i - F_j D_j}{F_i F_j - E_i E_j} \qquad (11)$$

Where, $D_i = \mu_i + M(\gamma C_j - \beta C_i)$, $E_i = 2(\gamma M B_i - \beta M A_i - \lambda_i {\sigma_i}^2)$ and $F_j = M(\gamma A_j - \beta B_j)$.

With the optimal wholesale prices, we can obtain the optimal retail price of retailer i

$$p_i^* = \frac{M[A_i(E_j D_i - F_j D_j) + B_j(E_i D_j - F_i D_i) + C_i(F_i F_j - E_i E_j)]}{F_i F_j - E_i E_j} \quad (12)$$

Thus, we have the expected utility of manufacturer i, the expected utility of retailer i, and the expected utility of supply chain i.

$$u_i^*(\pi_{Mi}^{DD}) = \frac{H_j(\mu_i G - \beta V_i + \gamma V_j) - \lambda_i H_j^2 \sigma_i^2}{G^2} \quad (13)$$

$$u_i^*(\pi_{Ri}^{DD}) = \frac{(V_i - H_j)(\mu_i G - \beta V_i + \gamma V_j) - \eta_i (V_i - H_j)^2 \sigma_i^2}{G^2} \quad (14)$$

$$u_i^*(\pi_{Si}^{DD}) = \frac{V_i(\mu_i G - \beta V_i + \gamma V_j) - [\eta_i (V_i - H_j)^2 + \lambda_i H_j^2]\sigma_i^2}{G^2} \quad (15)$$

Where, $G = F_i F_j - E_i E_j$, $H_j = E_j D_i - F_j D_j$ and $V_i = M(A_i H_j + B_j H_i + C_i G)$.

3.2. Two Competing Integrated Supply Chains

For an integrated supply chain, manufacturer i and his exclusive retailer i are fully aligned to achieve the supply chain's optimal performance (instead of manufacturer i and retailer i as two decision makers in the above section).

The profit of supply chain i is

$$\pi_{Si}^{II} = p_i(\alpha_i - \beta p_i + \gamma p_j) \quad (16)$$

Thus, the Mean-Variance value function of his profit is

$$u_i(\pi_{Si}^{II}) = E(\pi_{Si}^{II}) - \varphi_i D(\pi_{Si}^{II}) = p_i(\mu_i - \beta p_i + \gamma p_j) - \varphi_i p_i^2 \sigma_i^2 \quad (17)$$

For the first order conditions, we have

$$\frac{\partial u_i(\pi_{Si}^{II})}{\partial p_i} = \mu_i - 2(\varphi_i \sigma_i^2 + \beta)p_i + \gamma p_j = 0 \quad (18)$$

Notice that the second order derivatives are

$$\frac{\partial^2 u_i(\pi_{Si}^{II})}{\partial p_i^2} = -2(\varphi_i \sigma_i^2 + \beta) < 0 \quad (19)$$

So it follows that the optimal retail price of supply chain i is

$$p_i^* = \frac{R_i}{K} \qquad (20)$$

With the optimal retail prices, we can obtain the expected utility of supply chain

$$u_i^*(\pi_{Si}^{II}) = \frac{\mu_i K R_i - \beta {R_i}^2 + \gamma R_i R_j - \varphi_i {R_i}^2 {\sigma_i}^2}{K^2} \qquad (21)$$

Where, $K_i = 2(\varphi_i {\sigma_i}^2 + \beta)$, $R_i = K_j \mu_i + \gamma \mu_j$, and $K = K_i K_j - \gamma^2$.

4. Numerical Analysis

In this section, we will explore a numerical example. We choose the following parameter values to discuss the effects of demand uncertainty on the players' and supply chains' expected profits.

$$\mu_1 = \mu_2 = 10, \beta = 1, \gamma = 0.4, \eta_1 = \eta_2 = 0.2$$
$$\lambda_1 = \lambda_2 = 0.1, \varphi_1 = \varphi_2 = 0.3, \sigma_2 = 2$$

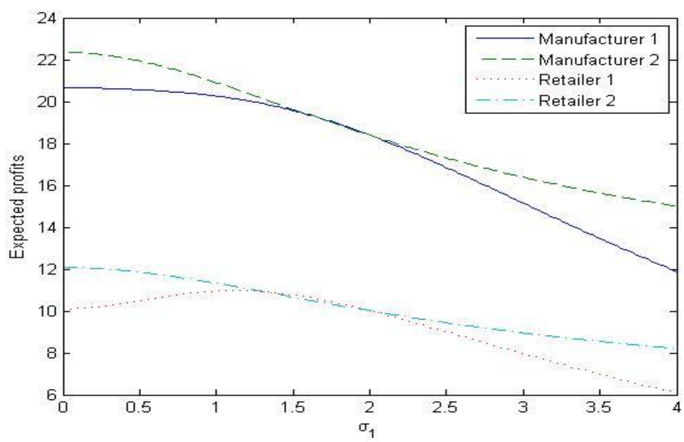

Figure 1: The expected profits of manufacturer 1, retailer 1, manufacturer 2 and retailer 2 versus the demand uncertainty of supply chain 1

Fig.1 plots the expected profits of two manufacturers and two retailers in both decentralized supply chains versus the demand uncertainty of one supply chain. From Fig.1, we know that the expected profit of one manufacturer is decreasing with the demand uncertainty of his own supply chain; the expected profit of one retailer is first increasing and then decreasing with the demand uncertainty of his own supply chain. That is, the retailer would like to offer a lower price to attract customers and can temporarily increase profits under demand uncertainty, and the manufacturer will share the market risks. We also know that the expected profit of one manufacturer and one retailer are decreasing with the demand uncertainty of the rival's supply chain. That is because the players' expected profits do not only depend on the demand uncertainty of themselves in the competing environments.

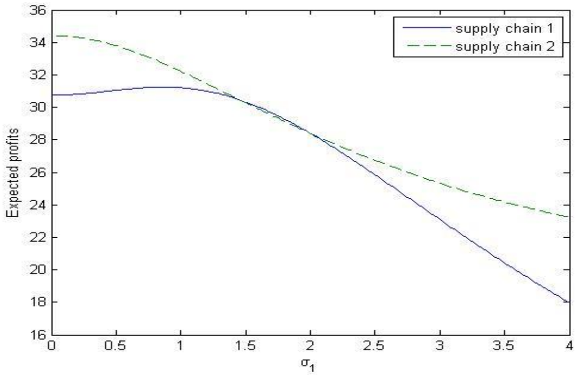

Figure 2: The expected profits of decentralized supply chain 1 and 2 versus the demand uncertainty of supply chain 1

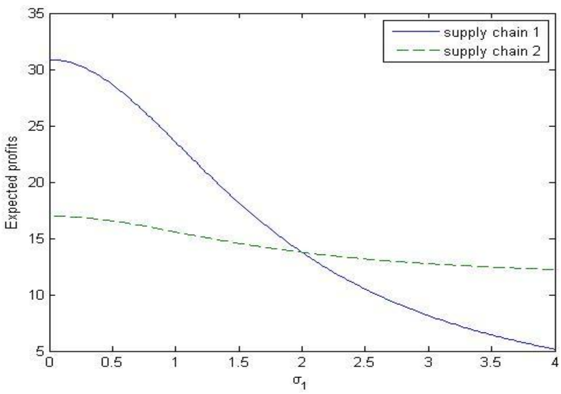

Figure 3: The expected profits of integrated supply chain 1 and 2 versus the demand uncertainty of supply chain 1

Fig.2 plots the expected profits of decentralized supply chain 1 and 2 versus the demand uncertainty of supply chain 1. From Fig.2, we see that the expected profit of one supply chain is first increasing and then decreasing with the demand uncertainty of him, otherwise is decreasing with the demand uncertainty of the rival's supply chain. This shows that, for two competing decentralized supply chains, an appropriate level of demand uncertainty can benefit one supply chain, but cannot benefit the other. Fig.3 plots the expected profits of integrated supply chain 1 and 2 versus the demand uncertainty of supply chain 1. From Fig.3, we see that the expected profits of both supply chains are decreasing with the demand uncertainty of one supply chain. This suggests that demand uncertainty has a bad influence to the industry profits.

5. Conclusion

We study the competition between two supply chains in a demand uncertainty environment. Each supply chain consists of one risk-averse manufacturer and one risk-averse retailer, where two retailers compete in retail price. Two supply chain structures: both chains are decentralized (DD) and both chains are integrated (II), are examined. We mainly discuss the effects of demand uncertainty on the players' and supply chains' expected profits. For two competing decentralized supply chains, we find that when the demand of one supply chain become more uncertain, the expected profit of himself is first increasing and then decreasing, but the rival's expected profit generally decreases. For two competing integrated supply chains, we find that the expected profits of supply chains both decrease as the demand becomes more uncertain. It is interesting to note that the expected profit of one supply chain does not only depend on the demand uncertainty of him.

There are several directions for future research. Firstly, a linear demand function in the price competition model is not without problem such as aggregate demand amplification. It is better for someone to adopt other competition models to study this problem. Secondly, we assume that the competing supply chains all have the same structure (either integrated or decentralized). It can be extended to the case where competing supply chains have different structures (such as one is integrated and the other decentralized). Finally, it is interesting but challenging to assume that retailers lie in more powerful positions, i.e., two retailers act as Stackelberg leaders.

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