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Price competition in duopoly supply chains with stochastic demand

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ABSTRACT

In the literature, substantial researches have been carried out on supply chain coordination. The majority of these studies suggest a mechanism that enforces the supply chain members to follow the strategies that produce the equilibrium of an integrated supply chain. Moreover, most of researches do not consider the competition among supply chains.

In this study, we consider an industry consisting of two distinct supply chains which compete with each other over price. Three algorithms are presented to calculate the equilibrium of three possible industry structures. It is assumed that demand is stochastic with additive form whose random component has a uniform distribution. Furthermore, the effect of competition and demand uncertainty intensity on the Nash equilibrium of the structures and supply chains' profits are discussed in a numerical example.

1. Introduction and literature review

One of the strategic decisions for a supply chain is to determine its structure. There are two types of structures: integrated and decentralized. In integrated supply chains, the members of supply chain are coordinated and they determine their decision variables to maximize the entire supply chain's profit. In decentralized supply chains, the members act independently and determine their decision variables to maximize only their own profit that may not maximize the entire chain's profit. Evidently in a monopoly environment, the integrated structure is optimal strategy. However, in a duopoly or oligopoly environment, in general, this may not hold.

One of the key ideas in supply chains is double marginalization [1]. By this notion, the supply chain members try to maximize only their own profits and they make margins for themselves which may cause that the entire supply chain does not earn its possible maximum profit. For example, in a two level decentralized supply chain, the retailer considers a margin and not only tries to set the retail price higher than its optimal quantity for the entire supply chain but also holds lower inventory quantity to reduces his/her costs. To eliminate the effect of double marginalization, the majority of researches present some models to coordinate the supply chain members. If there is another supply chain in the market, competition between these supply chains may force the retailers to set a lower retail price to earn more demand compared to their opponents or hold higher inventory. Therefore, the competition can offset the effect of double marginalization.

In this study, we investigate equilibrium behavior of two competing supply chains that compete with each other over price. It is assumed that both supply chains have two levels, manufacturer and retailer, and their retailers are faced with a uniform stochastic demand. We consider the industry structure in three forms: (1) both of the supply chains are integrated, (2) one of the supply chains is integrated and the other one is decentralized, and (3) both of the supply chains are decentralized. Three algorithms are presented to calculate the Nash equilibrium of the supply chains. Furthermore, the effect of variation of the uniform demand and substitutability of the supply chains' products which cause different degree of competition intensity are discussed in a numerical example.

In supply chain literature, competition between the same levels of supply chains is known as horizontal competition which is divided into two categories; in chain horizontal competition and chain to chain horizontal competition. In chain horizontal competition deals with the competition between different members of a supply chain in the same level. There are significant number of studies that consider in chain horizontal competition in manufacturer level such as [2–4]. Furthermore, in chain horizontal competition in retailer levels is considered in [5–12]. In addition, Adida and DeMiguel [13] consider in chain horizontal competition at both levels.

In this paper, we consider chain to chain horizontal competition, and investigate its effect on equilibrium behavior in a numerical

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example. Chain to chain horizontal competition deals with the direct competition between the members of the last level of different supply chains. McGuire and Staelin [14] perform a seminal study considering chain to chain competition. They investigate the effect of products substitutability or competition parameter on the Nash equilibrium distribution structures, and conclude that for highly substitutable products, the decentralized structure is preferred by both manufacturers. Following McGuire and Staelin, Coughlan [15] and Moorthy [16] explore the circumstances in which these results are held, and Choi [17] considers an extension of their model with one retailer that is able to sell both products. In another study, Choi [18] focuses on a channel structure in which there are duopoly manufacturers and duopoly common retailers. Wu and Chen [19] consider an industry with two competing supply chains and derive explicit equilibrium of different supply chain structures. Boyaci and Gallego [20] consider a market with two supply chains competing on the basis of customer service, and conclude that integrate structure for both supply chain is Nash equilibrium. Pekgun et al. [21] study two firms that compete based on their price and lead-time decisions in a common market, and investigate the Nash equilibrium of the structures. Xiao and Yang [22] develop a price-service competition model of two supply chains to investigate the optimal decisions of players under demand uncertainty. They analyze the effects of the retailer's risk sensitivity on the players' optimal strategies. Shou et al. [23] study the competition of two supply chains which are subjected to supply uncertainty. Wu et al. [24] investigate the equilibrium behavior of two competing supply chains in the presence of demand uncertainty. They indicate that using integrate structure for both chains is the unique Nash equilibrium over one period. Wu and Mallik [25] consider a supply chain system with two manufacturers; each producing a single substitutable product. They define cross sales to be the situation where at least one retailer sells both products, and analyze the cross sales in channels with different degree of integration. Anderson and Bao [1] consider price competition between supply chains, and extend the work of McGuire and Staelin in [14] to an industry with n supply chains.

We categorize the papers that study chain to chain horizontal competition according to both their competition basis (price and nonprice competition) and their demand function (deterministic and nondeterministic) in Table 1. As it can be observed, most of the papers belong to the first category in which the competition is based on price and demand function is deterministic. In the second category, there is only one paper by Wu et al. [24] in which the competition is based on price and demand function is nondeterministic. In their study, the authors consider the stochastic element in its simplest type with only two levels; high and low with probability u and $1-u$, respectively, where $0 \le u \le 1$. In the third and forth categories, the competition is not based on price. In the last two categories, the competition is based on the combination of price, service level, quantity and other criteria. In the sixth category which demand function is nondeterministic, there is only one research by Xiao and Yang [22]. They consider competition based on price and service level, and analyze the effects of the retailer's risk sensitivity on the players' optimal strategies. They do not report any analysis on how the chains' structure should be.

According to Table 1, there is a lack in researches on horizontal chain to chain competition on price with nondeterministic demand function. The main goal of this paper is to investigate horizontal chain to chain competition on price when the demand function has a stochastic distribution.

Game theory is a powerful tool to analyze the competition among several agents that have conflict or are cooperative in their payoff. In the literature, a large number of papers can be found which employ game theory to analyze the supply chains behavior. Two valuable reviews of the application of game theory in supply chain are [26] and [27]. Since we investigate the competition of two chains, the game theory techniques are employed as a natural approach for our analysis. Several concepts of game theory such as Nash Equilibrium (NE) and Stackelberg games are applied. An outcome of game is called NE, if none of the players could benefit by changing only his/her strategy. In other words, all of the players have their best response to the other's strategies. Stackelberg game has a leader and a follower in which the leader primarily chooses his/her strategy and then the follower observes this decision and makes his/her own choice of strategy.

This paper may have some important practical applications in real world. For example, IKCO and Saipa, which are two leading Iranian vehicle manufacturer, compete with each other in Iran's market. In most of the cities each of them has only one retailer. Apart from the decision on the price and production quantity, each manufacturer should also decide on his supply chain's structure. Our model can be used to assist these manufacturers in their problems.

The proceeding parts of this paper are organized as follow: In Section 2, the model is described. In Section 3, the NE of the model is investigated and three algorithms are presented in order to calculate the NE quantities. In Section 4, a numerical analysis is presented. Finally in Section 5, the conclusion is presented, and few suggestions for future research are offered.

2. The structure of model

An industry with two competing supply chains is considered. Each supply chain includes a manufacturer who sells his/her product via an exclusive retailer. Depending on the chain structure, integrated or decentralized, the retailer could be private or owned by the manufacturer. Each manufacturer produces a substitutable product. We equivalently index the supply chains and their members by $i, j = 1, 2$.

The chains compete with each other on the price; thus their retail price, denoted by p_1 and p_2, affects the market demand of two chains. We consider a demand function which consists of two deterministic and stochastic components. It is assumed that the deterministic component is as follows [1].

$$d_i(p_i, p_j) = ak_i - b'_i p_i + \gamma(p_j - p_i); i = 1, 2 \text{ and } j = 3 - i \quad (1)$$

where $\sum_{i=1}^{2} k_i = 1$. In this model, a is a parameter that provides the total potential market size (if all prices were 0), and k_i is product i's underlying market share; thus ak_i is the demand for product i if all prices were 0. In addition, b'_i and γ are nonnegative coefficients for the effect of prices on the chain's demand. When a supply chain increases its own retail price by a unit, its market demand decreases by $b_i = b'_i + \gamma$, and the demand for its competitor increases by γ. In fact, γ is competing parameter between two chains and indicates the demand leakage from one chain to the other chain. Eq. (1) is applied for deterministic component of demand using a change of variable $b_i = b'_i + \gamma$. Moreover, the additive form for the stochastic component is employed, as in [28]. Thus our demand model could be shown as Eq. (2).

$$D_i(p_i, p_j, \varepsilon_i) = (ak_i - b_i p_i + \gamma p_j) + \varepsilon_i \quad ; \quad i = 1, 2 \text{ and } j = 3 - i \quad (2)$$

where $(ak_i - b_i p_i + \gamma p_j)$ is the deterministic price dependent part of the model, and ε_i, for each i, is a nonnegative and independent random variable which has a uniform distribution function in $[-A, A]$. Yao et al. [11] utilize a model like Eq. (2) to analyze and coordinate a noncompeting supply chain.

The following three scenarios for industry structure are analyzed.