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Competitive closed-loop supply chain network design under uncertainty

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ABSTRACT

This paper studies the competition between two closed-loop supply chains including manufacturers, retailers and recyclers in an uncertain environment. The competition factors are the retail prices of new products and incentives paid to consumers for taking back the used products. Market demands are price sensitive and also the amount of returned products is sensitive to incentives. The primary goal of this paper is to investigate the impact of simultaneous and Stackelberg competitions between two closed-loop supply chains on their profits, demands and returns. A game theoretic approach which is empowered by possibility theory is applied to obtain the optimal solutions under uncertain condition. Finally the theoretical results are analyzed using sample data inspired by a real industrial case.

1. Introduction

To date, technology development, globalization of economy and unpredictable behavior of customers, has led to a competitive and dynamic environment in the marketplace [1,6]. These factors accompanied by the advanced infrastructures for e-business are changing the competition form of firms from independent individual type to supply chain vs. supply chain competition [1,4,6,10,12]. For example Microsoft (software supplier) and HTC (hardware manufacturer) compete as a supply chain against another chain consisting of Symbian (software supplier) and Nokia (hardware manufacturer) [1]. In these circumstances the following relevant questions arise: which supply chain will be the winner of the competition? What is the best network configuration for rival supply chains? How much market share the winner obtains? The aim of this paper is to cope with these questions analyzing the competition between two closed-loop supply chains in an uncertain environment.

Closed-loop supply chain (CLSC) has received tremendous academic and business attention in recent years as the social responsibility, environmental concerns and strict international regulations increased [8,11,13,15,48]. The CLSC combines forward and reverse supply chains to wholly cover the product life cycle from cradle to grave. Forward supply chain includes the logistic activities all the way from the raw material suppliers to the consumer and the reverse supply chain includes collecting, reproducing, recycling and disposal activities [8,11]. Many manufacturers such as GE Transportation, Xerox, Hewlett-Packard [9,14], IBM, Ford, Caterpillar and Timberland [3,7,16] have benefited from remanufacturing and CLSC networks. In 1996, Ford saved $180,000 from avoiding disposal of toner cartridges [5]. Collecting and remanufacturing more than 332,000 pounds of cartridges Ford achieved $1.2 million saving from 1991 to 1997 [5]. According to Gutowski et al. [17] remanufacturing in the United States is a $50 billion per year industry with direct employment of about 480,000. Due to the mentioned importance of CLSCs and the economic attractiveness in this area, many researchers have focused on designing CLSC networks to maximize value created from the integrated activities of forward and reverse chains [18]. On the other hand, the competition should be considered in the design of CLSCs as an important factor. The physical network design has a great effect on the performance of the whole chain and as a strategic decision plays the constraint role for other tactical and operational decisions [2].

There is a large literature on the topic of closed-loop supply chain network design (CLSCND). For a comprehensive review of published research works we refer the interested reader to the papers by Özceylan et al. [19], Pishvaee et al. [13] and Chanintrakul et al. [20]. In spite the great importance of competition in today's market which forces supply chains to improve or redesign their networks, most of the works in the literature did not considered

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the competitive factors in the network design phase. Based on the concept of competition in the supply chain network design (SCND) Farahani et al. [2] provide an overview of classifications of models and solution techniques. Three types of competition could be recognized from the relevant literature [21]: (1) Static competition: a new competitor (may be an individual firm or a supply chain) enters the market. The competitive characteristics of existing rivals are known and do not alternate after the entrance of new competitor [2,6,21]. This type of competition includes optimization of a mathematical model in which the new entrant decides about the strategic factors like facility locations [22–25,51]. (2) Competition with foresight: with entrance of a new competitor to the market, the existing rivals will change some of their characteristics with respect to decisions of the new entrant. This competition naturally is modeled as a Stackelberg game with a bi-level or multi-level programming problem [6]. (3) Dynamic competition: existing rivals change their competitive characteristics following the entrance of new competitor. Since the SCND strategic decisions (e.g. location and number of facilities) could not be changed due to the large amount of required investments, the competitive characteristics affect the operational level decisions such as price or service levels [2,6,21].

As the body of literature shows only a few research works address the chain to chain competition and most of the published research works consider the competition between two specific tires of a supply chain or between two or more firms in a single tire of a supply chain. McGuire and Staelin's [26] is one of the early works that introduced the concept of competition between two supply chains in the marketing research [27]. Wu and Chen [28] proposed a model for competition between two supply chains to analyze the equilibrium conditions for rival chains considering the inventory and return policies. Boyaci and Gallego [4] model the competition between two supply chains with one wholesaler and one retailer. The supply chains compete in a market and have to charge similar prices and compete on the customer service. They conclude that coordination is a dominant strategy for both supply chains to maximize their profit. Zhang [10] presented a general framework for modeling supply chain vs. supply chain competition. A variational inequality model is presented for the supply chain economy model in which heterogeneous supply chain competes for multiple markets. Xiao and Yang [1] presented a game theoretic model for price-service competition between two supply chains under demand uncertainty. One risk-neutral supplier and one risk-averse retailer are considered in the problem. The analysis shows that the risk sensitivity of a retailer has an inverse impact on its optimal service level and retail price. On the other hand substitutability of two products determines the effects of the rival's risk sensitivity on its decisions. Anderson and Bao [12] consider the price competition among more than two supply chains with linear demand function and identical structures in the vertically integrated and decentralized cases. They analyzed the effects of different levels of prices on the market players' profit. Most of the competitive models for rival chains did not take into account strategic decisions and assume that the structure of the supply chains is fixed and pre-known. Rezapour and Farahani [21] proposed a model for two competing chains with identical products and price-dependent demands in a deterministic environment. The strategic (i.e., location) and tactical (i.e., inventory and shipment) decisions are also considered in the proposed model. Variational inequality approach presented by Nagurney et al. [29] is applied to formulate the problem. In addition, Rezapour et al. [30] present a network design model for a supply chain which enters a market with rival chains. They consider a static competition between new entrant and pre-existing rivals. Rezapour et al. [6] also developed a model for competing supply chains with foresight. Following the entrance of a new chain the existing chain has a tendency to open new retailers to recapture some income. They model the problem using von Stackelberg and minimum regret approaches. In the former approach the existing competitor decided to optimize its market share through opening some new facilities in the future and the latter approach is a game against nature and the existing chain's future facilities are unpredicted.

Almost all of the reviewed research works in the area of competitive SCND only focus on the forward supply chain activities under deterministic condition. Considering returns management to the forward supply chain models adds new decision variables to the model and we have to decide on the amount of reverse flows, the quantity of recycled materials, number of recycling centers and price of returned products that increases the complexity of the model. On the other hand, integrating the design of forward and reverse supply chains avoids sub-optimalities resulted from separated design of forward and reverse supply chains [13,49,50]. However, supply chain networks naturally work in an uncertain and dynamic environment [31]. Klibi et al. [31] presented a review paper on SCND problem under uncertainty and risk. They identify the sources of uncertainty in the SCND problem and accordingly classify the relevant optimization methods and models. Due to difficulties in the estimation and control of the quantity and quality of returned products the degree of uncertainty increases in CLSCs problems [32]. To cope with uncertainties, various stochastic programming approaches are developed in the literature (see [31]). However, the lack of historical data in most of real case problems prevents us to obtain a random distribution function for uncertain parameters. Moreover, using the chance constrained or scenario based stochastic programming approaches can significantly increase the complexity of computations [33]. In these situations fuzzy set theory [35] can be used as an alternative framework since it can be used to model the uncertain parameters based on managerial judgments and experimental data [33,34,42]. In the competitive CLSC literature the existing works consider different decisions in the reverse channel such as pricing [5,18,37,38], collecting mode [8,36], collection rate and remanufacturing choice [9,11]. These works address the operational decisions under competition and they considered inter-chain relations of firms but also neglected the intra-chain competition and do not account for the impact of the reverse channel characteristics on the strategic network decisions.

In this paper two closed-loop supply chains competing in an uncertain environment are taken into account. The considered CLSCs compete on retail price for new products in the forward chain and incentive quantity (payment amounts given to consumers who take back used products) in reverse chain. The market demand for each supply chain is price sensitive and also the amount of returns is sensitive to incentive quantity. Fuzzy set theory is applied to model the imprecision of input parameters. Two competition scenarios are considered for the closed-loop supply chains: (1) simultaneous competition; which the new SC enters to market and decides on its network configuration (i.e. the location and number of facilities) and tactical characteristics (i.e. quantity of production, shipments, return and recycled products) regarding the decision of the existing chain. (2) Stackelberg competition; which in this situation, following the entrance of new chain, the existing chain will change its operational decisions based on the characteristics of new competitor and subsequently the new chain will decide on its retail and reverse prices. Here the existing chain is leader and the new one is follower.

The major contributions of this paper which distinguishes this research from the other mentioned works in the literature can be summarized as follows: (1) considering the competition between two closed-loop supply chains on the retail prices and incentive quantity which has not been addressed in prior studies. Most of the existing papers in the competitive supply chain literature focus on the inter-chain competitions (e.g. manufacturer-retailer