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Effects of Reconfigurations for Multi-period Production Planning under Demand Uncertainty

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Abstract

We address the effects of the exchanges of leader-follower relationship to the multi-period supply chain planning under demand uncertainty. Most of conventional works assume that the leader-follower relations for multiple companies are treated as constant in all time periods. However, in order to accommodate changes caused by uncertainties, it is necessary to develop reconfigurable supply chain that can flexibly change its structure of supply chain according to the dynamical changes of manufacturing environment. In this paper, a multi-period supply chain planning model that can change the structure of supply chain over time periods under uncertainty is developed. We provide a novel production planning model that can effectively determine the optimal configuration of leader-follower relationship in the bilevel supply chain planning problem. Then, the total profit of the supply chain is analyzed by a game theoretical analysis. The effects on the change of configurations are investigated from computational experiments.

Keywords: supply chain optimization, dynamic reconfiguration, game theoretical approach, demand uncertainty

1. Introduction

Supply chain management has been remarkably progressed due to global production. Supply chain coordination is a mechanism to achieve a total optimization for multiple enterprises. It is well-known that decentralized decision making under competition among these companies makes the total profit lower than centralized decision making. This is called double marginalization. The game-theoretical approach has been playing an important role in developing efficient coordination mechanisms in supply chain management.

Conventionally, most of the game theoretical approaches for production planning problems assume that the leadership structure in supply chains has been unchanged. However, in order to deal with uncertain situations such as manufacturing environment, supply chain risks and changes, reconfigurable supply chains that can flexibly and dynamically change its structure is required.

The impact of the leadership structure in supply chains on overall supply chain efficiency has been studied in many previous studies (Choi, 1991 [3], Trivedi, 1998 [10], Choi and Fredj, 2013 [4], Chung and Lee, 2016 [2], Sakurai et al. [9]). Most of these studies focus on only pricing game in supply chains. In the pricing game, supplier determines wholesales price to retailer, and the retailer determines product price to customers. No prior study has been conducted for the dynamic change of the leadership structure in multi-period production planning problems in supply chains.

In this paper, we address the effects of dynamic change of the leadership structure for two-echelon supply chain planning problem. The production planning problem is formulated as a bilevel programming problem. The determination problem of

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the optimal leadership structure is formulated as a mixed integer nonlinear programming problem. The effects of the changes of the leadership structure is studied in several case studies.

This paper is organized as follows. Section 2 introduces literature review. Section 3 states the problem definition and the mathematical formulation of the dynamic optimization of the leader-follower relationship with a single supplier and a single retailer for our problem setting. The reconfiguration problem for leadership structure is introduced in Section 4. Computational experiments are conducted in Section 5. Section 6 concludes this study.

2. Literature review

Xiao et al. (2014) investigated the product variety and channel structure strategy when the retailer is a pricing leader and manufacturer is a pricing follower [11]. Pan et al. (2010) studied two scenarios of contract selection that the manufacturer can choose wholesale price contract or revenue-sharing contract as a leader and that the retailer can choose them as a leader [8]. Choi (1991) addressed the impact of the supply chain configuration to the total profit. The supply chain configuration to the total profit of two companies and the retailer from the manufacturer's side in case of two manufacturers and one retailer [3]. Trivedi (1998) studied the case where the manufacturer side of two companies or the retailer side of two companies became the leader, respectively [10]. Choi et al. (2013) discussed the influence of the case where a manufacturer is a leader and two retailers are leader side of the pricing decision problem with one manufacturer and two retailers [4]. They also discussed a vertical three echelon structure of a leader-follower relationship. However, in these studies, the structure is rather simple and they did not consider all possible leader-follower structures.

In the game theoretical approach on coordination of supplier and manufacturer has been studied for many years. Nishi et al. (2008) developed a decentralized optimization technique to the coordination of production planning for multiple companies [7]. Yin and Nishi (2014) developed a solution procedure for supply chain planning with supplier selection under demand uncertainty [12]. The problem has been formulated as mixed integer nonlinear programming problem. The problem is constructed only for manufacturer's side of decision making. Yin et al. (2015) developed an optimal coordination model for both from a manufacturer and multiple suppliers [13]. The decision making problem is modelled as a Stackelberg game where the manufacturer is a leader and the suppliers are the followers. Nishi and Yoshida (2016) presented a concept of reconfigurable supply chains [6]. Yoshida et al. [14] addressed an analytical approach for the Stackelberg equilibrium and an optimal quantity discount contract for multi-period production planning for a single supplier and a single retailer. Nishi and Yoshida (2016) studied the effects of the replacement of leadership structure for supply chain planning demand uncertainty [15]. However, the decision making problem for the automatic determination of leadership structure has not been studied in those conventional works.

3. Multi-period production planning problem for two-echelon supply chains under demand uncertainty

3.1 Problem definition

This work consider a single manufacturer and a single retailer. Demand is uncertain but the probability distribution is known. The retail price and wholesale price are given in advance. The lead time for production, transportation and distribution are constant. The manufacturer determines production quantity for each item to the retailer. The retailer determines the order quantity to satisfy customer's demand. The manufacturer can deliver on time any quantity ordered by the retailer. At the beginning of each period, manufacturer sets a unit wholesale price for the period and the retailer orders a quantity at the price to satisfy the demand which will be observed only at the end of the period when it is no longer possible to adjust the order quantity. The manufacturer decides the wholesale price per unit products which maximizes the supplier's profit.
The two-echelon supply chain is shown in Figure 1.

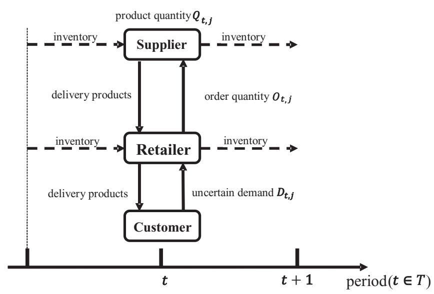

Figure 1. Multi-period supply chain model for single supplier and single retailer.

The manufacturer incurs unit production cost and sells at a unit wholesale price. The manufacturer's profit function is the total wholesale profit minus total production cost over the time horizon. All parameters are remaining unchanged over the periods and demands of each product at each period are independent. Demand is assumed to follow a probability distribution. The information about density and cumulative probability function, mean and variance is known in advance. Sales of products from the retailer to customer are not lost if the demand exceeds the inventory. The retailer decides the order quantity to the supplier under uncertain demands. The retailer incurs unit inventory holding cost and unit penalty of shortage cost.

The retailer's profit function is the expected value of the total sales minus the sum of the inventory holding costs, penalty costs of the stock shortage and wholesale costs. To make the discussion easier, this work consider a non-cooperative situation between a single manufacturer and a single retailer.

3.2 Problem formulation

Zhang et al. (2009) [16] formulated a multi-period production planning model where the decision variable is the cumulative