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Coordinating pricing and inventory decisions in a multi-level supply chain: A game-theoretic approach

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ABSTRACT

This paper concerns coordination of enterprise decisions such as suppliers and components selection, pricing and inventory in a multi-level supply chain composed of multiple suppliers, a single manufacturer and multiple retailers. The problem is modeled as a three-level dynamic non-cooperative game. Analytical and computational methods are developed to determine the Nash equilibrium of the game. Finally, a numerical study in computer industry is conducted to understand the influence of the market scale parameter and the components selection strategy on the optimal decisions and profits of the supply chain as well as its constituent members. Several research findings have been obtained.

1. Introduction

A supply chain consists of geographically distributed and administratively decentralized business partners. In such a decentralized supply chain, decisions of individual partners are often not coordinated with each other. Their local objectives are often inconsistent with those of the entire system objectives. As a result, the supply chain becomes less competitive (Porter, 1985). Many firms and researchers focus on coordinating pricing and inventory decisions to optimize the entire system and improve the efficiency of both the supply chain and individual firms (Weng, 1995; Chan et al., 2004).

Typically, a supply chain involves a variety of multiple products that are related to each other through common features. The levels of product variety offered by supply chains have demonstrated increasing trends (Macduffie et al., 1996). The product family design and platform products development have been widely used to increase variety, shorten lead times, and reduce costs (Simpson, 2005). The research in this paper has been motivated to integrate the product family design and platform products development into the pricing and inventory decisions to coordinate a decentralized supply chain.

This paper focuses on joint decision-making about the selection of suppliers and components of a product family (Meyer and Utterback, 1993). The emphasis is placed upon the coordination of suppliers and components selection, pricing and inventory decisions (CSCSPI) in a multi-level supply chain consisting of multiple suppliers, one manufacturer and multiple retailers. The manufacturer purchases optional components of certain functionality from his alternative suppliers to produce a set of platform products to meet the requirements from the retailers in different markets. Each supplier faces the problem to make decisions on the prices for the components he sells to maximize his net profit. The manufacturer has to determine the setup time interval for production, the wholesale prices, and the suppliers and components selection decisions to maximize his net profit. The retailers' problem will focus on the replenishment cycles and retail prices for the products.

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We describe CSCSPI problem as a three-level dynamic non-cooperative game with respect to the overall supply chain. The suppliers formulate the bottom-level non-cooperative simultaneous sub-game and at the same time as a whole play the middle-level non-cooperative simultaneous sub-game with the manufacturer. The suppliers and the manufacturer also being a group formulate the top-level non-cooperative simultaneous whole game with the retailers. Once the whole game settles an equilibrium solution, none of the any chain members is able to improve its payoff (i.e. profits) by acting unilaterally without degrading the performance of other players. We propose both analytical and computational methods to obtain the Nash equilibrium of this game.

The game model and the proposed solution algorithm constitute a powerful decision support for solving the CSCSPI problem. Its use is demonstrated and tested through a numerical example. The impacts of the market scale parameter and components selection on the decisions and profits of all the chain members are also investigated.

This paper is structured as follows. The next section presents a brief review of the literature related to pricing and inventory coordination, product family design, Game Theory for supply chain coordination. In Section 3, we give the problem description and some notations. We formulate the mathematical model of the CSCSPI problem in Section 4. Section 5 proposes the analytical and computational methods used to solve the CSCSPI problem in Section 4. In Section 6, a numerical study and the influence of market scale parameter and the components selection strategy have been presented. Finally, this paper concludes in Section 7 with some limitations and suggestions for further work.

2. Literature review

Pricing, inventory decisions, and product family design and platform products development, have been extensively studied in supply chain coordination. Although the three areas are closely interrelated with each other, they are rarely been studied in an integrated, systematic manner. Recently, Game Theory (GT) has also been applied to analyze supply chain coordination problem. This section will briefly review a few representative works related to this research.

2.1. Coordination of pricing and inventory decisions

Coordinating pricing and inventory decisions of supply chain has been studied by researchers for more 50 years. Whitin (1955) shows that the retailer could obtain greater profits when coordinating the price and order quantity decisions. Kunreuther and Richard (1971) find the same results for the inter-department coordination in a manufacturer and a retailer. Based on their work, Tersine and Price (1981), Arcelus and Srinivasan (1987), Ardalan (1991), Martin (1994), and Abad (2003) draw the same conclusions in various circumstances. Kim and Lee (1998) examine the joint pricing and lot sizing problem for a profit-maximizing firm facing constant and price dependent demand with both fixed and variable capacity. Weng and Wong (1993) and Weng (1997) propose a model of seller–buyer relationship and confirm that coordinated decisions on pricing and inventory benefit both the individual chain members and the entire system. Boyaci and Gallego (2002) analyze the problem of coordinating pricing and inventory replenishment policies in a supply chain consisting of a wholesaler, one or more geographically dispersed retailers. They show that optimally coordinated policy could be implemented cooperatively by an inventory-consignment agreement. Prafulla et al. (2006) present a set of models of coordination for pricing and order quantity decisions in a one manufacturer and one retailer supply chain. They also discuss the advantages and disadvantages of various coordination possibilities. These studies on the coordination of pricing and inventory decisions problem focus on individual entities or two-stage channels.

2.2. Product family design and platform strategy

Thonemann and Bradley (2002) study the impact of product variety on supply chain performance. Kohli and Sukumar (1990) deal with a joint problem of designing a set of optional products to maximize the manufacturer's profit. Various models have been derived for designing the product family instead of a single product to reduce the cost concerns of increased product variety, as Yano and Dobson (1998) reviewed. Chakravarty and Baum (1992) formulate a product family model incorporating process selection and use it to illustrate the interactions with some marketing and manufacturing variables. Saurabh and Krishnan (1999) examine the reduction in complexity of a product family by product design. Park and Simpson (2005) show the benefits of different resource sharing methods related to product family design.

Meyer and Lehnerd (1997) define product platform as the shared common components, product structure and manufacturing assets by a product family. The advantages to design products based on platforms are demonstrated in component demand patterns, work center load, work-in-progress inventory and delivery performance (Collier, 1981). Sanderson and Mustafa (1995) show the impacts of using a platform strategy on the amount of product variety offered by a company. There are also a few model-based approaches to creating products based on platforms. Krishnan et al. (1998) propose a way to obtain an optimal platform-based family based on a network model for products that can be measured along a single performance index that may increase with time.