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Coordination of pricing and leadtime quotation under leadtime uncertainty

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ABSTRACT

In many service and make-to-order manufacturing firms, pricing and leadtime quotation are two of the most important decisions. We consider a firm that serves customers who are sensitive to both price and quoted leadtime, with pricing and leadtime decisions being delegated to the marketing and production departments, respectively. According to the power structure within the firm, we model the problem as a Nash game, production Stackelberg game, and marketing Stackelberg game. For each game, the unique equilibrium is derived. In addition, for each decentralized setting, we design a mechanism that can be used by the firm to coordinate the decisions of the production and marketing departments. It is observed that the coordination schemes in the different games are of the same form. In particular, we find that the detailed values of the coordinating transfer prices under different power structures are the same. Moreover, we demonstrate that under some mild conditions on the level of the potential demand, the marketing Stackelberg game Pareto-dominates the Nash game in terms of expected profits.

1. Introduction

In today's markets, it is commonly found that price is no longer the unique basis on which customers decide to buy a product. For instance, Baker, Marn, and Zawada (2001) have reported that less than 10% of end customers and less than 30% of corporate customers base their purchasing decisions only on price, whereas for a substantial majority of customers, both price and delivery leadtime are the prominent factors that determine their purchasing decisions. Accordingly, to gain competitive advantages, more and more firms have devoted themselves to providing a low selling price as well as timely customer service. In these firms, pricing and leadtime quotation are the two decisions that are of great importance.

In many firms, it is common that pricing and leadtime quotation decisions are delegated to the marketing and production departments, respectively. Generally, production department is a cost center that focuses on improving operational efficiency and lowering cost, whereas marketing department is a revenue center that seeks to maximize total revenue and profit. Since the roles played by the marketing and production departments are different, it follows that the performance measures adopted by the two departments are considerably different. When the two departments make decisions based on optimizing their local objectives, it is inevitable that the decisions being made in a way that is suboptimal to the firm as a whole. It can be guessed that the firms performance will be improved if there are some well-designed schemes to be used to coordinate the two departments.

In this study, our goal is to investigate the impact of decentralizing the production and marketing departments of a firm where pricing decisions are made by the marketing department and leadtime quotation decisions by the production department. We model the demand as a function of both the price and the quoted leadtime. According to the power structure within the firm, we divide the analysis into three distinct parts. When the production and marketing departments have equal power, we model the problem as a Nash game. In addition, when either production or marketing is the dominant function, the problem is formulated as Stackelberg games with alternative decision-making sequences, where production is the leader and marketing is the follower in the first setting, and marketing is the leader and production is the follower in the second setting. In the sequel, these two settings are termed as the production Stackelberg framework and marketing Stackelberg framework, respectively.

In formulating the objective functions of production and marketing in the decentralized setting, we assume that the firm sets a fixed transfer price to make both of the departments profit centers. Moreover, because the actual leadtime is random and is

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always inconsistent with the quoted leadtime, we introduce the leadtime-related costs, which include the echelon holding cost and the tardiness penalty cost, in the production department's expected profit function. Finally, to reflect the fact that the probability distribution of the leadtime is dependent on the demand process, we assume that the random leadtime is expressed as the product of the expected demand during the selling season and a random variable that is independent of the demand process.

In summary, we focus in this research on (1) demonstrating the existence and uniqueness of the equilibrium solution in each decentralized setting; (2) illustrating the impacts of the marketing factors (i.e., the level of the potential demand as well as the price and leadtime sensitivities to the demand) on the unique equilibrium solution in each decentralized setting; (3) designing coordination mechanisms that can align the incentives of production and marketing with the firm's overall objective in each decentralized setting; (4) showing numerically how close the performances of different decentralized systems are to the integrated solution if the firm simply uses the fixed transfer price; and (5) identifying the conditions under which the firm must adopt the coordination mechanisms.

The remainder of this paper is organized as follows. After a review of the relevant literature in the next section, we provide the model basics that include notations and assumptions in Section 3. In Section 4, we derive the optimal decisions in the centralized setting, which are used as a benchmark against which to measure performances in different decentralized settings. In Sections 5 and 6, we derive the equilibrium solutions and illustrate how the equilibrium solutions change with respect to each marketing factor in the Nash and Stackelberg frameworks, respectively. Numerical studies are conducted in Section 7. Finally, we summarize the results in Section 8. All proofs are provided in the Appendix.

2. Related literature

There are two streams of research related to this study: (1) the simultaneous management of pricing and leadtime quotation and (2) the interactions between production and marketing. In accordance with whether the firm makes price and leadtime quotation decisions contingent on the state of the system, the former can be further divided into two major categories: dynamic quotation and stationary quotation. In recent years, the dynamic quotation of price and leadtime has been paid more and more attention by researchers (see, e.g., Afèche, 2013; Afèche & Pavlin, 2011; Ata & Olsen, 2013; Çelik & Maglaras, 2008; Feng, Liu, & Liu, 2011). However, stationary quotation is still of great interest because it is simpler for firms to implement. In this study, we focus on stationary price and leadtime quotation decisions and, thus, only review the literature in this direction. Palaka, Erlebacher, and Kropp (1998) consider a firm with the objective of maximizing revenues minus the total variable production costs, congestion-related cost, and tardiness penalty costs over price and quoted leadtime, where the demand is treated as a linear function of the two decision variables and the firm's operations are modeled as an $M/M/1$ queueing system. So and Song (1998) use the log-linear Cobb–Douglas demand function to model the demand in a similar setting. So (2000) extends So and Song (1998) to the case of competition with N firms. Boyaci and Ray (2003) study a case of two substitutable products for which dedicated capacities are allocated. Recently, Wu, Kazaz, Webster, and Yang (2012) propose a model that enables the firm to simultaneously determine the optimal ordering quantity, selling price, and quoted leadtime under leadtime and demand uncertainty. The linear demand model in Palaka et al. (1998) and the multiplicative random leadtime model in Wu et al. (2012) are used in this study. However, the aforementioned studies all focus on integrated decisions, whereas we discuss the decisions in a decentralized setting.

The second research stream concentrates on the joint decision making of the production and marketing departments of a firm. We refer to Tang (2010) for a comprehensive review on the issue of coordination in the context of production–marketing interfaces. In this stream, most works focus on the coordination of pricing and replenishment decisions (see, e.g., Dewan & Mendelson, 1990; Eliashberg & Steinberg, 1987; Kouvelis & Lariviere, 2000; Kumar, Loomba, & Hadjinicola, 2000; Li & Atkins, 2002; Porteus & Whang, 1991) or of pricing and quality selection (see, e.g., Balasubramanian & Bhardwaj, 2004). There are only a small number of papers examining the coordination of pricing and leadtime quotation. Liu, Parlar, and Zhu (2007) consider a decentralized supply chain and demonstrate the inefficiencies stemming from the decentralization of price and leadtime decisions. They model the problem as a Stackelberg game where the supplier serves as the leader and the retailer serves as the follower. Further, they emphasize the decision inefficiencies resulting from the double marginalization in the supply chain.

In this research stream, the work most related to ours is that of Pekgün, Griffin, and Keskinocak (2008). They study a decentralized system where price and leadtime decisions are made by the marketing and production departments, respectively. The customer demand is considered as a linear function of price and quoted leadtime, as in Palaka et al. (1998), and two Stackelberg games that consider the production department as the leader and the marketing department as the leader, respectively, are investigated. The main differences between our study and that of Pekgün et al. (2008) are as follows: (1) They only consider the variable production cost in formulating the objective functions, while our model includes the leadtime-related costs. Because the actual leadtime is random, inclusion of the leadtime-related costs may be necessary. (2) In Pekgün et al. (2008), the firm's operations are modeled as an $M/M/1$ queueing system, and, thus, the leadtime can be expressed as the steady-state customer sojourn time. However, the $M/M/1$ leadtime distribution is under some restrictive assumptions that are not consistent with the practical manufacturing environment. As a result, in this study, we make use of the multiplicative random leadtime model introduced by Wu et al. (2012). As Wu et al. (2012) point out, the class of multiplicative leadtime distributions is general enough to capture the settings in most studies. (3) Pekgün et al. (2008) only consider the situations under which production or marketing is the dominant function within the firm, whereas we discuss three different decentralized settings in accordance with the power structure within the firm. Besides the production and marketing Stackelberg frameworks, this study considers the situation in which the production and marketing departments have equal power. (4) The coordination mechanisms developed by Pekgün et al. (2008) are contingent on the frameworks, whereas we find that the coordination schemes in different decentralized settings are of the same form. In particular, we find that the detailed values of the coordinating transfer prices under different power structures are the same.

Note that Hu, Guan, and Liu (2011) also use Nash and Stackelberg games simultaneously to study the coordination mechanisms for the manufacturing and sales departments. They concentrate on solving the leadtime hedging issue. Therefore, the modeling frameworks and the conclusions are all different from ours.

3. Model basics

We consider a firm with fixed capacity that serves customers in a make-to-order fashion. As Shang and Liu (2011) state, the