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Dynamic lot-sizing models with pricing for new products

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ABSTRACT

While previous dynamic lot-sizing (DLS) models mainly consider mature products, this study analyzes production planning decisions for new products. The demand dynamics caused by new product diffusion complicate production decisions for new products. We integrate DLS and discrete Bass models to provide optimal decisions for pricing and production planning problems. Moreover, we study the joint influence of product diffusion and pricing parameters on the DLS decisions. This leads to the following insights. First, coordinated production-pricing and dynamic pricing improve profitability. Second, the optimal pricing strategy is affected by market conditions. The penetration pricing strategy outperforms the skimming pricing strategy when consumers are less sensitive to relative price changes than to the introductory price, when the product diffuses slowly, or when the consumer initiative level is low. Otherwise, the latter outperforms the former. Finally, pricing strategies and product diffusion patterns reshape the cost structure of a firm. Coordinated decisions and dynamic pricing strategy substantially reduce the cost-revenue ratio, whereas an increase in the consumer initiative level or product diffusion speed can improve cost efficiency.

1. Introduction

New products are crucial for modern firms, with sales derived from new products accounting for an average of 28% of firm sales in the United States (Cooper, 2011; Crawford & Di Benedetto, 2008). Our research interest is motivated by production planning problems in a biochemical company in France, which faces dynamic demand when introducing a new patented product, with a monopoly in the period of patent protection. This firm is sufficiently capable in ensuring the supply of the new patented product, that is, the production capacity is assumed to be unlimited. The new product management (NPM) division of this company has exerted efforts to promote the product. However, determining the production time and quantities is difficult because of the dynamics and complexity of the new product diffusion process. Another example is a fitness equipment retailer in China that needs to manage inventory replenishment problems when promoting patented fitness equipment. On the one hand, replenishment causes high fixed cost, and storage requires additional space and maintenance cost. On the other hand, stockout may result in the loss of consumers. Thus, replenishment decision becomes essential and challenging for new products.

These firms hope to design an appropriate production policy to handle the complex dynamics of new product diffusion, as well as coordinate production planning and NPM. Such complexity lies in two aspects. First, the demand for new products is dynamic and depends on the diffusion pattern. Second, the NPM division constantly uses specific pricing strategies to promote a new product or earn profits. For example, the NPM division may adopt penetration pricing to build a large sales volume, or skimming pricing to make use of consumers' insensitivity to initial high prices (Noble & Gruca, 1999). Therefore, a well-designed production policy calls for a thorough understanding of the new product diffusion pattern and the effects of pricing strategies. The sales and production sections in the NPM division should cooperate closely, as well as simultaneously consider production and pricing decisions (Bajwa, Sox, & Ishfaq, 2016; Gong, 2013; Hausman, Montgomery, & Roth, 2002).

To handle demand dynamics in new product diffusion, we adopt the dynamic lot-sizing (DLS) models to optimize the production planning, since most enterprises implement enterprise resource planning systems comprising a manufacturing resource planning (MRP) modular in making production decisions

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(Gunasekaran, Marri, McGaughey, & Nebhwani, 2002). One assumption of the lot-sizing decision in MRP is that the demand is deterministic (De Bodt, Gelders, & Van Wassenhove, 1984). Although the uncertainty of demand appears in the diffusion process of new products, such uncertainty can be handled using a rolling scheme or using the safety stock while applying the DLS techniques (De Bodt, Van Wassenhove, & Gelders, 1982). DLS problems have been proven to be an efficient model in handling dynamic demand (Wagner & Whitin, 1958). Researchers have been extending the DLS problems in various settings. For reviews that focus on model category, algorithms, and demand patterns, see Bahl, Ritzman, and Gupta (1987), Karimi, Fatemi Ghomi, and Wilson (2003), Brahimi, Dauzere-Peres, Najid, and Nordli (2006), and Jans and Degraeve (2007). Most lot-sizing models are used to solve production or inventory planning problems for mature products (De Bodt et al., 1984). Our research follows this stream by applying an uncapacitated DLS model in dealing with the production planning problem in a new product environment, which has seldom been considered before. Moreover, we consider the Bass model in specifying the demand in the new product diffusion.

We investigate the production planning problem for new products with pricing decisions. In particular, we combine the DLS model with the generalized Bass model that incorporates price effects. This approach enables us to analyze the coordinated production and pricing decisions for new products, thereby providing beneficial guidelines for the firm. Accordingly, we attempt to answer the following questions: How do we make optimal production decisions considering the dynamics of new product diffusion? How do we coordinate and make pricing and production decisions considering the dynamics of new product diffusion?

Our contributions are as follows. First, we provide new insights into coordinated production and pricing, as well as optimize production planning according to different new product diffusion patterns. Second, we consider the DLS problem in the context of new products. Only a few studies combine the Bass model with production decisions. Finally, we attempt to coordinate pricing strategies and the DLS concerning different product diffusion patterns. Our research closely relates the growing research stream on coordinated pricing and production management in various settings (see, e.g., Yano and Gilbert, 2004, and Chen & Simchi-Levi, 2012), but focuses on new product situations.

2. Literature review

Our study mainly relates to three research domains: coordinated production and pricing models, DLS models with pricing, and Bass-based product diffusion models.

This research is categorized in the growing research stream on coordinated pricing and production or inventory management (see review papers of Eliashberg and Steinberg, 1993, Yano and Gilbert, 2004, and Chen & Simchi-Levi, 2012). Recent studies investigate coordinated decisions in various settings such as multi-item cases (Bajwa et al., 2016), perishable or substitutable products (Sainathan, 2013), backordering (Bernstein, Li, & Shang, 2016), random yield (Eskandarzadeh, Eshghi, & Bahramgiri, 2016), free shipping (Hua, Wang, & Cheng, 2012), cost learning (Li, Sethi, & He, 2015), and reference price effect (Güler, Bilgiç, & Güllü, 2015; Wu, Liu, & Zhang, 2015). Most of these studies consider continuous-time models or stochastic models. By contrast, our study uses discrete-time models with price-dependent deterministic demands, as well as incorporates the reference price effect.

Since the seminal work of Wagner and Whitin (1958), the DLS problems have been vastly studied. We can easily find several reviews on the related research topics, such as modeling approaches and algorithms (e.g., Bahl et al., 1987; Karimi et al., 2003; Brahimi et al., 2006; Jans & Degraeve, 2007). Researchers have extended lot-sizing problems in various settings, such as product returns (Teunter, Bayindir, & van den Heuvel, 2006), fixed carbon emissions (Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, & Rapine, 2016), capacity reservation contract (Akbalik, Hadj-Alouane, Sauer, & Ghribi, 2017), and online retailers (Xu, Gong, Chu, & Zhang, 2017). Our study is most relevant to the integrated DLS problem with pricing, which often appears in the interface of operations and marketing management. Based on the results of Wagner and Whitin (1958), Thomas (1970) studies the first discrete-time lot-sizing model in a new setting by regarding prices of each period as decision variables. Then Kunreuther and Schrage (1973) consider a similar problem in which the price is assumed to be constant over the entire planning horizon and develop a heuristic solution approach. Gilbert (1999) and Van den Heuvel and Wagelmans (2006) investigate the same problem as Kunreuther and Schrage (1973) and provide polynomial-time methods under the assumption of stationary costs and time-varying costs alternatively. While the demand in a given period is assumed to be independent of the prices offered in adjacent periods in most relevant papers, Ahn, Gümüs, and Kaminsky (2007) consider a much realistic scenario where the demand in each period depends on prices of multiple periods. Scholars have also addressed issues of coordinating DLS and pricing decisions with other factors, such as perishability of products (Bhattacharjee & Ramesh, 2000), restriction of production capacity (Geunes, Merzifonluoğlu, & Romeijn, 2009), and competition from multiple products (Bajwa et al., 2016). We consider integrated lot-sizing and pricing decisions in the context of new products, analyze both constant and dynamic prices under different product diffusion patterns, and evaluate their effects on production decisions.

The Bass model has been extensively used to model new product diffusion and forecast demand (Bass, 1969; Peres, Muller, & Mahajan, 2010). Furthermore, a firm can stimulate product diffusion via pricing, advertising, or channel disintegration (Bass, Krishnan, & Jain, 1994; Ramanan & Bhargava, 2013). Generalized versions of the Bass model consider the effects of prices (e.g., Robinson & Lakhani, 1975) or their changes (e.g., Bass et al., 1994). Our study adopts the discrete form of the Bass model and incorporates the effects of prices and their changes. Incorporating production decisions enables our research to provide additional insights into new product pricing. Only a few studies integrate the Bass model with production or inventory decisions. For example, Shen, Duenyas, and Kapuscinski (2013) examine the optimal inventory decisions for new products by focusing on the effect of supply constraints. Bilginer and Erhun (2015) analyze when to launch a new product concerning inventory-related costs and product diffusion pattern. A similar work by Bhattacharya, Guide, and Van Wassenhove (2006) examines production policy for new products, but without considering the diffusion pattern. By contrast, we combine the DLS and the Bass models, as well as focus on the strategic choice among constant, skimming, and penetration pricing strategies.

3. Dynamic lot-sizing models for new products

3.1. Problem description

We consider a firm that introduces a new product into the market. Consumers gradually learn the existence and quality information of the new product. The product diffuses via two types of communication channels, namely, mass media and word of mouth (Bass, 1969). The consumer purchases at most one unit of the product over the entire planning horizon. Therefore, the demand at period t equals the number of new adopters $n(t)$, that is, $d(t) = n(t)$. This relationship holds for many products, such as smartphones and cameras. Our model can easily consider multi-item or repeat purchases. If every adopter purchases w units of