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Dynamic ordering and pricing strategies in a two-tier multi-generation durable goods supply chain

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ABSTRACT

This paper considers the problem of dynamic pricing and ordering decisions for a durable product with multiple generations in a supply chain with one manufacturer and one retailer. The manufacturer introduces a new generation of the durable product before the last generation exits from the market. Demands for the product are quality- and price-sensitive. For each generation, the manufacturer determines the wholesale price and quality level; the retailer decides order quantity of the generation and its retail prices in every purchase period. Both the manufacturer and the retailer want to maximize their respective expected profits. In order to study the impact of consumer's behavior on a decentralized supply chain, our model uses a more accurate purchase probability according to a consumer's past purchasing experience to reflect a quality- and price-sensitive demand. We show that the retailer's optimal pricing strategy exists and depends only on the consumer's quality- and price-sensitivities for a given product quality. We also show that there is an optimal ordering strategy for the retailer. Consequently, the manufacturer projects a quality level and a wholesale price according to the retailer's optimal strategies. We use a numerical example to illustrate our results.

1. Introduction

In general, durable goods are purchased due to their useful physical function and relative long product life cycle. Products such as refrigerators, electric heaters, cars, laptops, sports equipment, and household goods, etc. are commonly considered as durable goods. However, some new features emerge and become important factors in consumers' decision making due to the rapid product innovations and shortened product life cycle. For example, consumers tend to care more about cell phones' fashionable characteristics, automobiles' special packages, or the convenience of online shopping for household products. These changes make manufacturers introduce new products more quickly and consumers buy durable products more frequently. Thus, in a durable product supply chain, it becomes much more important to study how to improve and manage the product quality and how to price and order the durable goods with different successive generations while considering consumers' preferences in order to obtain 'win–win' scenarios.

Since the Apple Inc. introduced its first internet- and multimedia-enabled smartphone on January 9, 2007 and released it on June 29, 2007, in less than 5 years, Apple has released iPhone, iPhone 3G, iPhone 3GS, iPhone 4, and recently the 5th generation iPhone, the iPhone 4S, on October 14, 2011. The expectation on the sixth generation, iPhone 5, on the horizon, consumers must consider the option of buying earlier generations of iPhone or wait to buy the new generation iPhone. With sales revenue sky-rocketing and frequent new generation introduction, the Apple has to make significant innovation (or quality improvement) in its newer generation and phases out its earlier generations of iPhones without completely cannibalizing its current products. Currently, iPhone 3GS, iPhone 4, and iPhone 4S co-exist in the market with different pricing strategies and meet different customer's preferences.

This paper considers both pricing and ordering decisions by the retailer, both pricing and quality decisions by the manufacturer in a durable products supply chain with one manufacturer and one retailer. The manufacturer introduces new generations of the product before the last generation exits from the market. Demands for the products are both quality-sensitive and price-sensitive. For each generation of the product, the manufacturer sets the wholesale price and quality (or performance) level, and the retailer decides order quantity of the generation and its retail prices in every purchase period. Each generation of the durable product's price could decrease three times during its life cycle

(see for example, iPhone). The objectives for the manufacturer and the retailer are to maximize their respective expected profits in a decentralized setting. Our goal is to analyze how the price- and quality-sensitivities affect the supply chain members' strategies.

Our work is closely related to the literature in dynamic pricing of durable goods, multiple products pricing, combined ordering and pricing, quality level strategies, and durable goods' consumers' sensitivities. We briefly review the most relevant work to clarify the contribution of the paper.

Durable goods make up a large fraction of economy and play an important role in the generation and propagation of business cycles (Deneckere and Liang, 2005). Thus, durable goods pricing is becoming a vital topic in economics studies. The Coase conjecture argues that the price is equal to the competitive market price since a durable goods monopolist has no market power (Coase, 1972). However, Fehr and Kuhn (1995) think that consumers realize and anticipate the price of the goods will only fall when they purchase the good. Therefore, a patient monopolist can exercise full market power and perfectly price discriminate. Balachander and Srinivasan (1998) assert that the decrease of the price over the product life cycle is common among durable products, such a phenomena can be traced to the theory of experience curve or learning curve.

In the operations management literature, dynamic pricing for durable products and pricing for durable goods with multiple versions are well studied. Dhebar (1994) models a problem of a durable-goods monopolist selling two sequential versions of a product in a setting with no second-hand markets. Dhebar shows that no equilibrium exists with rapid technological changes due to the incentive to set a low second period price by the monopolist to attract new consumers. Subsequently, Fudenberg and Tirole (1998) analyze the pricing problem for a sequentially innovating durable-goods monopolist by considering three types of consumers: anonymous consumers with second-hand markets, identifiable consumers with no second-hand markets, and semi-anonymous consumers with no second-hand markets. Kornish (2001) extends the analysis in Dhebar (1994), and finds that if the monopolist does not segment the market in the second period (i.e., does not offer special upgrade pricing), then an equilibrium pricing strategy exists.

The consumer is also a key element in dynamic pricing strategies. In a two-period model, Balachander and Srinivasan (1998) consider a firm that introduces a durable product at the beginning of the first period using the introductory signaling strategy. The optimistic expectations of customers reduce their willingness to pay a high price at the product's introduction while predisposing them to buying later. They demonstrate that a high introductory price will signal a low experiential learning to customers. Ray et al. (2005) categorize two distinct types of durable goods customers: first-time buyers and customers who already own the product and are willing to replace it with a new one or purchase a second one. They develop a pricing framework for a durable product and show that the firm gains more from price discrimination than customer segmentation. There are also some papers considering competition between manufacturers (c.f., Desai and Purohit, 1999; Heese et al., 2005; Krishnamoorthy et al., 2010).

There have been several studies dealing with the pricing problem in the durable goods supply chain. Bhaskaran and Gilbert (2009) focus on how product durability affects the inter-actions between a manufacturer and her dealers by considering a durable goods manufacturer that uses independent dealers to get her product to consumers. Xiong et al. (2012) also address the products durability and its impact on players' optimal strategies in a dual-channel supply chain. They show that the equilibrium

quantities and wholesale prices become quite angular and often nonmonotonic as the direct selling cost decreases. Chiang (2011) extends the single-period vertical price interaction in a manufacturer–retailer dyad to a multi-period setting. A manufacturer distributes a durable product through an exclusive retailer to an exhaustible population of consumers with heterogeneous reservation prices. The main result is that both supply chain entities are better off in the long run when they ignore the impact of current prices on future demand and focus on immediate-term profits.

The papers mentioned above contribute much to durable goods pricing. However, little work focuses on pricing the durable goods with multiple versions in a dynamic supply chain. In addition, previous research on pricing strategies did not address every consumer's purchasing behavior although it is very common in the retailing practice. Therefore, there is a need to study more on dynamic pricing of multiple products not only in their product lifetime, but also for different consumers.

Other related work study the combined pricing and ordering strategies of common products. Rajan et al. (1992) develop continuous time pricing and ordering policies when the demand is deterministic. Weng (1997) develops optimal pricing and ordering strategies in a manufacturing and distribution system consisting of one manufacturer and one distributor. The system operates to meet price-sensitive random demand. Federgruen and Heching (1999) address the simultaneous determination of pricing and inventory replenishment strategies for one firm facing demand uncertainty. They characterize the structure of an optimal combined pricing and inventory strategy. Bernstein and Federgruen (2003) consider a similar problem with one supplier and multiple competing retailers. Chen and Bell (2009) address the simultaneous determination of price and inventory replenishment when customers return products to the firm. They derive results for the optimal prices and order quantities and discuss how the firm should change price and inventory quantities in order to mitigate the negative effects of returns from customers. Jia (2009) analyzes production capacity competition among manufacturers, and ordering quantities and pricing competitions among retailers in a supply chain network. The combined pricing and ordering a product with different brands is also considered.

The joint of product quality and price is of vital importance to not only consumers, but also manufacturers. However, little work has been done on it. Mukhopadhyay and Setaputra (2007) develop a profit-maximization model to jointly obtain optimal policies for the product quality level, price, and the return policy over time. The model presented in their paper is dynamic in nature and considers the decisions as the product moves through the life cycle.

Another literature describes the products demand affected by consumers' purchase behavior and consumers' sensitivity to buy durable goods. Researchers discuss consumers behavior of buying durable goods in the perspective of their effects on firms' pricing decisions and demand (Liu et al., 2007; Bayus, 1992); their perceived values (Zeithaml, 1988; Patterson and Spreng, 1997; Banerjee and Bandyopadhyay, 2003; Wathieu, 2004; Sanchez et al., 2006); and repeat purchases (Kurata and Nam, 2010). Researchers have been recognizing the importance of the individual consumer's sensitivity to the firms' policies in the supply chain. Popescu and Wu (2007) prove that the steady state price set by a monopolist is decreasing with consumers' memories and their sensitivity to the reference price when studying the dynamic monopoly pricing issue, and that the consumer with a high loss aversion will lead to a higher pricing flexibility. Liberali et al. (2005) analyze the effect of the quality- and price-sensitivities of consumers on the optimal marketing mixed (price and quality) strategies.

However, to the best of our knowledge, no studies have been conducted on the effect of consumers sensitivity on strategies in a