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Optimal inventory and pricing policies for remanufacturable leased products

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ABSTRACT

In this paper we consider a company which leases new products and also sells remanufactured versions of the new product that become available at the end of their lease periods. When the amount of end-of-lease items in stock is not sufficient to meet the demand for remanufactured products, the firm may purchase additional cores from a third-party supplier. We develop a dynamic programming formulation for determining the optimal price of remanufactured products, and optimal payment structure for the leased products. Our objective is to maximize the discounted system-wide profit over a finite horizon. The profit function consists of revenues that are obtained from remanufactured product sales and leasing, remanufacturing and manufacturing costs, inventory holding and shortage costs. We consider a consumer choice based demand model for mapping a potential customer into one of the product segments (a remanufactured product customer or a customer for a leased product with a particular lease period) for a given price/lease payment vector. We explore several properties of the discounted profit function and provide insight on the behavior of pricing and inventory policies. We also investigate the effect of key product characteristics such as deterioration in age, cost of shortage in remanufacturable product inventory, and key market characteristics such as relative willingness-to-pay for buying a remanufactured product and relative willingness-to-pay for leasing a new product on optimal pricing policies through a computational study.

1. Introduction

Remanufacturing (in the context of our paper) is the process of bringing a used product to an as-good-as-new condition by inspecting its components and performing repairing, replacing, restoring operations as necessary. A product is considered remanufactured if its primary components come from a used product. Recently, remanufacturing has been receiving growing attention for various reasons such as consumer awareness, environmental concerns, economical benefit, and legislative pressure. Remanufactured products include photocopiers, computers, telecommunication equipment, cellular phones, automotive parts, office furniture, and tires. One of the major issues faced by the firms involved in remanufacturing is taking back used products before the end of their useful life so that some revenue can be generated by remanufacturing or reusing them. Another concern is the uncertainty in the quantity, timing and quality of returned products. At this point, leasing turns out to be a viable strategy that helps to better manage the return process.

Leasing is a widely used business strategy in United States. According to the U.S. Equipment Leasing and Finance Association (http://www.elfaonline.org/), in 2005 U.S. leasing organizations financed $248 billion of a total of $800 billion in business equipment investments. Leasing helps a firm in getting a consistent flow of used products for remanufacturing, which in fact reduces the uncertainty in the quantity and timing for returns. Furthermore, it has a positive impact on better forecasting the quality of returns at the end of their lease time because of the periodic maintenance activities performed by the firm. As a consequence, leasing allows firms to control the quality, quantity and timing of product returns, which is a primary concern of many remanufacturing initiatives.

Besides the benefits of leasing for the manufacturer, consumers also have advantages when they lease a product instead of buying them. As such, they pay for the service provided by the product rather than for the product itself. Note that only a portion of the product's price is paid, which corresponds to the proportion "used up" during the lease period. Moreover, leasing products like computers makes it easier for customers to sooner upgrade to the newest technology. Certainly, product characteristics affect the viability of a lease. For example, nondurable products are not suitable for leasing since little value remains at the end of the lease period to be captured, so that no product recovery becomes possible except recycling that is considered to be the least desirable recovery form.

In this paper, we consider a firm leasing one type of a new product, and selling remanufactured versions of this products.

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Hence, we assume that the product is durable and remanufacturable. Our main objective is to determine in a multi-period setting the best prices so as the profit of the firm is maximized. Customers in the market are assumed to be heterogeneous in their willingness-to-pay and they perceive the value of remanufactured products less than the new products. Customers are assumed to be grouped in different segments where each segment corresponds to customers who are interested in a certain lease period. Customer preference in each segment is modeled using a maximum utility type approach in which customers make their choice of leasing a new product, buying a remanufactured product, or buying nothing based on the utility they derive from each choice. Leased products return at the end of the lease agreement. This implies that at the beginning of each period we exactly know how many cores will be returned. Therefore, the supply of used products depends on past lease volumes of new products. If returned products in stock are not sufficient to meet demand for remanufactured products in any period, the manufacturer may obtain extra used products from a third-party core supplier. In our inquiry, we attempt to answer the following questions: (1) What are the optimal prices in each period? (2) How do the factors such as deterioration in age and cost of acquiring used remanufacturable products from the third-party core supplier influence the optimal price in each period? (3) How does customers' perception of remanufactured products with respect to new products affect the optimal pricing strategy?

We make three contributions in this paper: (i) we present a decision making framework for products that are leased to customers and that can be remanufactured upon their return, (ii) we develop a dynamic programming formulation for determining the optimal prices for the leased and remanufactured products along with optimal quantities to lease and to remanufacture, (iii) we present a computational study that provides managerial insight on the factors affecting these pricing and quantity decisions. The remainder of the paper is organized as follows: Section 2 includes a literature review about leasing, and pricing-oriented papers within the context of remanufacturing. Problem description and model formulation are given in Section 3. Section 4 includes the solution procedure. Experimental results are presented in Section 5. We conclude in Section 6.

2. Literature review

We provide a brief literature review on leasing and pricing within the remanufacturing context. Particularly, we group the relevant literature into two classes: papers with an emphasis on decision making in a leasing environment and papers that jointly consider remanufacturing and pricing.

A recent review of supply chain literature within the context of environment conscious manufacturing and remanufacturing can be found in Srivastava (2007). Leasing as a means of transaction is playing an increasingly important role in marketing durable goods. On the other hand, leasing is also becoming a pervasive phenomenon in our ordinary life. For instance, many durable goods that are traditionally sold to consumers can now be leased too. The spectrum of leased durable goods is rapidly expanding. Examples of these include such daily necessities as cars, furniture, computers, and other electronic appliances (Huang and Yang, 2002).

Mont et al. (2006) propose a business model that integrates leasing and remanufacturing strategies for baby pram manufacturers. They argue that, with appropriate design changes that enable easy and cheaper remanufacturing, utilizing the leasing option is expected to generate long-term sustainable profits, which otherwise would be lost to the second-hand market.

Fishbein et al. (2000) have examined the practice of leasing products, rather than selling them, as a strategy for increasing resource productivity, particularly by preventing waste generation and moving to a pattern of closed-loop materials use. They mention many companies that successfully acquire products through leasing and remanufacture returned products.

Desai and Purohit (1998) analyze the problems associated with marketing a durable through leases and sales. Their goal is to understand the strategic issues associated with concurrently leasing and selling a product and determine the conditions under which this concurrent strategy is optimal. Desai and Purohit (1999) examine competition in a duopoly; they investigate a firm's rationale in choosing an optimal mix of leasing and selling and to understand how it is affected by the nature of competition in the market and the embedded quality in the product. They argue that a competitive environment forces firms to adopt strategies where they only sell their products or use a combination of leasing and selling. The model proposed by Sharma (2004) allows electronic equipment leasing companies to simultaneously make optimal decisions about lease lengths, product flows and end-of-life product disposal.

There is a growing literature in operations management that combines remanufacturing, pricing of new and remanufactured products as well as competition and marketing. These studies try to determine the optimal selling prices of remanufactured and new products to maximize the profit of the company. Groenevelt and Majumder (2001) develop a two-period model to examine the effect of competition in remanufacturing considering a original equipment manufacturer (OEM) and a local remanufacturer. The demand faced by the players is modeled as a function of the selling prices of both players. OEM and the local remanufacturer compete to capture as much market profit as possible. Ferrer and Swaminathan (2006) analyze a model where remanufactured and new products are not distinguishable to the customer. They analyze two-period and multi-period scenarios where the manufacturer only produces the new product in the first period, but has the option of making new and remanufactured products in subsequent periods. They also consider a duopoly environment where an independent remanufacturer may obtain cores to sell remanufactured products in future periods.

The effect of competition on recovery strategies has also been examined by Ferguson and Toktay (2006). They propose two strategies: remanufacturing and preemptive collection. Preemptive collection is a strategy to discourage competition so that manufacturer collects part or all of the items, but does not recover the residual value of the used product. They argue that a firm may prefer to remanufacture or preemptive collection to deter the entry of third party remanufacturers into the market, even when the firm would not have chosen to do so under a pure monopoly environment. The study of Debo et al. (2005) is the first study that addresses the integrated market segmentation and production technology choice problem in a remanufacturing setting where the supply of used products that can be remanufactured depends on the past sales volumes of new products and the level of remanufacturability. They solve the joint pricing and production technology selection problem faced by a manufacturer that considers introducing a remanufacturable product in a market that consists of heterogeneous customers.

As an example of papers that consider quality of remanufactured products explicitly, Mitra (2007) models an environment where remanufactured products and refurbished products have different quality levels and hence have different price levels to be decided so as to maximize revenue.