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OEM product design in a price competition with remanufactured product

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ABSTRACT

An original equipment manufacturer (OEM) produces new products and often faces a dilemma when determining the level of interchangeability in its product design. The interchangeability is considered as a degree to which the product can be disassembled without force, and thus an increasing degree of interchangeability would decrease the OEM's production cost, but it would also lower a remanufacturer's cost in cannibalizing used items. Decreasing the level of interchangeability to deter the remanufacturer, on the other hand, would simultaneously increase the production costs of the OEM. We thus formulate a two-period supply chain model consisting of two chain members, an OEM and a remanufacturer, to investigate the product design decision of the OEM and both chain members' competitive pricing strategies. We then characterize the equilibrium decisions and profits with regard to costs and consumers' preference for the remanufactured product. We also evaluate a strategic game in which the OEM chooses the degree of interchangeability, and the remanufacturer determines its collection strategy. We find that the product-design strategy is effective for the OEM in competing with the remanufacturer, but it is not necessarily harmful to the remanufacturer.

1. Introduction

Remanufacturers are motivated by the prospect of obtaining economic benefits to go into the business of processing and selling remanufactured products. These remanufactured products are made from products that were initially produced by original equipment manufacturers (OEMs) but were collected and cannibalized for reuse after they had reached the end of their useful lives. Remanufacturing systems reduce production costs and place less of a burden on the environment because they require less raw materials and less expensive production processes. As defined by Ijomah et al. [1], remanufacturing is a process of restoring a used product to like-new condition by rebuilding it, replacing certain components, and providing a warranty for the remanufactured product that is at least as good as the warranty for a new product. Thus, remanufactured products meet the demand of consumers who desire low-priced, environmentally friendly products that have like-new quality. The profitability of remanufacturing has resulted in accelerated growth in the remanufacturing industry. An important contributing factor is the high interchangeability found in the design of many remanufactured products [2], such as automotive parts [3], personal computers, cameras, mobile phones [4], and toner cartridges [5]. It is difficult and costly to restore used items that were not designed for remanufacturing [6,7]. An interchangeable design may involve different design features, such as design for modularity or design for disassembly. In this paper, we focus on interchangeability relating to the degree to which the product can be disassembled without force [8], which affects the ease of cannibalization.

A design which allows for interchangeability may be beneficial for OEMs because it also allows for ease of inspection, handling, and cleaning [9]. Thus, an interchangeable design would seem to be a "win–win" strategy if the OEMs and remanufacturers were not in direct competition with each other. When OEMs and remanufacturers are in competition with each other, however, some OEMs may adjust their strategies by decreasing design interchangeability to maintain their profits. In the printer-cartridge industry, for example, a Gartner report [10] indicates that printer OEMs are losing their revenues, which may exceed $13 billion in 2010, because of the competition of low-cost remanufactured products. The substantial threat that is posed by remanufactured products is causing certain OEMs to reconsider their own strategies by also selling remanufactured products, but most OEMs still do not remanufacture their products. Ferguson [11] suggested that most OEMs may be unwilling to handle remanufactured products because they focus most of their time and resources on their new product sales, or because they lack the infrastructure and expertise to collect and remanufacture used units profitably. For example, Hewlett-Packard declared its policy to produce only single-use print cartridges and not to offer remanufactured cartridges [12]. Furthermore, certain printer OEMs try to deter remanufacturers with an ultrasonic welding

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technique or unnecessary adhesive tape in the assembly process to reduce the interchangeability of used cartridges [5]. Two cartridge remanufacturing associations in Europe, UKCRA (The UK Cartridge Remanufacturers Association) and ETIRA (European Toner & Inkjet Remanufacturers Association), explained several of the approaches that printer OEMs use in assembling products (e.g., a sonic welding technique or unnecessary adhesive tape) to deter remanufacturing. This phenomenon also occurs in other industries [5,13]. A product's design interchangeability and the availability of used items also influence the decisions of OEMs and remanufacturers regarding prices. For these reasons, an investigation of the level of interchangeability that OEMs choose to accept in their product designs, and of the collection strategies adopted by remanufacturers when they compete primarily based on price, may provide interesting insights.

The literature on remanufacturing has concentrated primarily on the market segmentation between OEMs and the competing remanufacturers (see, for example, [14–24]). For example, Majumder and Groenevelt [20] examined how a remanufacturer is constrained by the availability of used items when it collects used items that were sold by an OEM in the first period and uses the remanufactured products to compete with the OEM in the second period. Ferrer and Swaminathan [17,18] also examined the relationship between new and remanufactured products in their investigation of competition in monopoly and duopoly environments under finite- and infinite-horizon models. On this basis, they characterized the OEM's equilibrium results and remanufacturer's collection decisions. The entry of a remanufacturer into a market has generally been found to hurt the profitability of the OEM. Therefore, several studies have discussed how the strategic choices of OEMs affect remanufacturers' decisions, including their entry choices. For instance, Debo et al. [15] focused on the influence of the OEM's choice of product technology on the level of remanufacturability and on the chain members' profits in an infinite-horizon setting. Debo et al. [19] further considered how an OEM can choose to collect used products preemptively to deter the entry of the remanufacturer. These authors also identified the cost conditions under which the preemptive-collection strategy would be profitable for an OEM.

Compared to OEMs, remanufacturers could potentially enjoy savings in terms of both material costs and process costs. However, the manufacturers' actual savings are substantially affected by the interdependent product-design decisions and marketing choices of the OEMs [25]. Product-design decisions include operational choices, such as level of interchangeability. A decision to use modular designs may cause returned products to have a greater salvageable value because they can easily be dismantled and reused [26]. Modular designs also result in a higher degree of interchangeability [27,28] and may facilitate commonality and economies of scale, thereby lowering the cost of assembly [29,25] while decreasing the inventory quantities of components. Hua et al. [30] discussed the effect of the product-design strategy on the remanufacturer's quality and price decisions for the low-end and high-end segments of the market. The study by Hua et al. captured the effect of product design on the interaction among decisions by the supply chain members. Maukhopadhyay and Setoputro [26] proposed the use of a modular design as a viable strategy to retain a high salvageable value for returned products because products that embody modular designs are easily dismantled and reused, leading to a smaller value reduction. Other studies [27,28] indicated that the interchangeability of the product design also creates cost savings during production because the cost of assembly is reduced and economies of scale are more easily achieved. However, these studies on the advantages of interchangeability only focused on certain issues (e.g., quality improvement, production cost savings, reuse of return items), and they neglected the impact of product design on pricing decisions. By applying qualitative data analysis methods, several studies have shown that product design is an important factor for remanufacturing (e.g., [2,6,13,31,32]). For example, Gray and Charter [13] to recent developments in remanufacturing and concluded that a good product design enables firms to resolve inefficiencies in remanufacturing and increase their own profit margins. Ijomah et al. [33] explained that welding and strong-adhesive design types in assembly increase the difficulty of remanufacturing. With respect to strategy in remanufacturing, Teunter [34] discussed the disassembly and recovery strategy through a stochastic dynamic programming algorithm. However, to the best of our knowledge, no study on remanufacturing has yet modeled the interaction between the pricing decisions of chain members and the level of interchangeability chosen by the OEMs in their product design that affects the chain members' production costs. To address this gap in the literature, we consider the level of interchangeability chosen by OEMs within a competitive environment under a two-period horizon.

The remainder of this paper is organized as follows. In Section 2, we derive the market demand of the new and remanufactured products from the utility functions of consumers, and formulate the firms' profit functions. Then, we solve for the equilibrium decisions in the presence and absence of product-design strategy. Section 3 analyzes the equilibrium decisions and the product-design effects. In Section 4, we further analyze the equilibrium profits, and develop a strategic game to study the interaction between the OEM's choice of product design and the remanufacturer's choice of collection. The final section concludes the study with a brief summary and points to potential future research directions.

2. The model

We consider a supply chain consisting of two chain members over two periods: in the first period, an OEM chooses the level of interchangeability in the product design and sells a new product to the market, and in the second period, a remanufacturer collects and cannibalizes the used products that were sold by the OEM and sells the remanufactured products. A product designed with high interchangeability (i.e., where a highly disassemble design was adopted) will be efficient both to assemble as a new product and to disassemble for cannibalization, while a product designed with low interchangeability will directly increase the production cost for the OEM and the cost of cannibalization for the remanufacturer [13,26,32,35,36]. In the first period, the OEM may decide to not strategically manipulate the level of interchangeability in its product design, or it may explicitly consider the degree of interchangeability in terms of the tradeoff between the benefits to itself and to the remanufacturer. In the second period, the remanufacturer may or may not determine the collection rate, which relates to the available quantity for remanufacturing [31]. We apply the two common assumptions of multiple-period models with remanufacturing [14,17,19,20,37]. The first assumption is that a new product purchased in the first period cannot provide positive utility for the customers in the second period; thus, the product has a useful lifetime of only one sale period. This assumption allows us to claim that the consumers' purchasing behaviors across the two periods are independent. The second assumption is that other products in the dedicated market and other markets have no effect on the demand of the products under consideration. This assumption allows us to focus specifically on the competition between remanufactured products and new products. Lastly, we also assume that the firms are risk-neutral and profit-maximizing and that they have complete information [38,39].