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Strategic and operational decisions under sales competition and collection competition for end-of-use products in remanufacturing

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ABSTRACT

Providing incentives to customers for recycling their end-of-use products is a commonly adopted strategy by remanufacturers for achieving economic scale of remanufacturing. However, the entrance of remanufacturers threaten the sales of new products that are produced by original equipment manufacturers (OEMs). Thus, OEMs may also take back end-of-use products by providing incentives to restrict the capacities of remanufacturers. Consequently, OEMs and remanufacturers compete not only on prices in sales market but also on incentives in recycle market. Therefore, we formulate a closed-loop supply chain model consisting of an OEM and a remanufacturer to investigate their equilibrium prices and incentives. Moreover, we consider that the remanufacturer can strategically focus the economies of scale on the sales market or on the recycle market. We derive the equilibrium decisions and profits under each of the remanufacturer's strategies, and identify the characteristics of these equilibrium results. We further derive the conditions to determine the firms' behaviors toward the competition. We also find that the higher competitiveness in the sales market will encourage the remanufacturer to focus the economic scale on the recycle market instead of the sales market, which is also beneficial to the OEM.

1. Introduction

Remanufactured products are made from used products, which were initially produced by original equipment manufacturers (OEMs), through a process that restores them to a "like-new" condition. This process, as defined by Ijomah et al. (2004), involves recovering and replacing certain components and providing a warranty for a remanufactured product that is at least as good as the warranty for a new product. Our study focused on "end-of-use" products (Atasu et al., 2008; Geyer et al., 2007; Neto et al., 2010) the useful lives of which have been exhausted but that can be restored to their original functions through remanufacturing rather than be discomposed for material reuse or parts. From an environmental standpoint, remanufacturing of end-of-use items instead of disposing of them is considered as a proven measure to improve the sustainability of supply chains. Remanufacturing systems reduce production costs and place less of a burden on the environment because they require fewer raw materials and less expensive production processes. Thus, remanufactured products provide economic benefits for remanufacturers to enter into the industry and to meet the demand of consumers who desire low-priced, environmentally friendly products that possess a "like-new" standard of quality.

According to a Gartner report (Tripathi et al., 2009), in the printer-cartridge industry, competition from low-cost remanufactured cartridges caused printer OEMs to experience a decline in sales revenues for new printer cartridges, which are forecasted to exceed $13 billion in 2010. In the automotive industry, a business report announced by Global Industry Analysts (2010) forecasted worldwide automotive remanufacturing to reach $104.8 billion by 2015. In the face of such a great threat from the remanufacturing industry, many OEMs try to deter remanufacturers through strategic changes, such as introducing OEM-remanufactured products (Atasu et al., 2008; Ferguson and Toktay, 2006), alternating product design (Wu, 2012b, 2013), or reducing the remanufacturability of products (Debo et al., 2006), thus undermining remanufacturers' competitiveness. The aforementioned studies also revealed that the impacts of OEM-deterrent strategies are associated with market- and cost-related factors and are sometimes harmful to OEMs. Hence, the strategic interactions between OEMs and remanufacturers, in addition to their interactions on operational decisions (e.g., price or quantity decisions), are important issues in remanufacturing. Furthermore, some OEMs aggressively collect end-of-use products in recycle markets to restrict the availability of used cores for remanufacturers; for example, Kodak

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collected the end-of-use cores of single-used cameras to prevent market cannibalization by remanufacturers (Bulmus et al., 2014). Besides preventing remanufacturers, Bulmus et al. (2014) indicated that economic benefit (e.g., cost savings) is a key factor driving OEMs to collect and reuse end-of-use products.

However, firms' strategic interaction in recycle markets, though not uncommon, has not been explored in the literature. For example, many office product retailers, such as Staples, OfficeMax and Office Depot, recycle end-of-use printer cartridges by providing a reward ranging from $2 to $5 per unit and then sell the remanufactured cartridges at a lower price than printer OEMs. To respond to this market cannibalization of remanufactured products, reward programs that provide incentives to the recycle market and restrict the quantities of end-of-use items available to remanufacturers were introduced by printer OEMs, such as the Lexmark return program and the Hewlett-Packard PurchasEdge program. Thus, printer OEMs and remanufacturers compete both on prices in sales markets (price competition) and on incentives, such as financial rewards and discount coupons, in recycle markets (incentive competition). In such an environment, the following questions, though likely to be encountered by OEMs and remanufacturers in practice, have not been adequately addressed in the literature:

- Under what circumstances should OEMs strategically provide incentives to recycle markets in competing with remanufacturers?
- Under what circumstances should remanufacturers pursue economies of scale in sales markets, or should they change to achieve economies of scale in remanufacturing?
- How do OEMs react in response to remanufacturers' recycling strategies?
- How does incentive competition affect the firms' pricing decisions?
- How do factors such as cost savings, scale of recycle market, and consumer preferences for remanufactured products affect firms' equilibrium results?

To gain intuition regarding these questions, we develop a theoretical model that formulates price competition in a sales market and incentive competition in a recycle market between an OEM and a remanufacturer. To our knowledge, no previous research has simultaneously considered the firms' interactions in the sales and recycle markets at both the strategic and operational levels.

The remainder of this paper is organized as follows. Section 2 reviews the literature relevant to this study. In Section 3, we formulate the market demand for OEM and remanufacturer products from consumer utility functions and formulate profit functions of firms. Moreover, we derive the equilibrium prices and incentives where each firm's incentive is determined by his/her collection strategy. Section 4 analyzes and characterizes the equilibrium decisions and profits and discusses analytically and numerically. The final section concludes the study with a brief summary and points to potential future research directions.

2. Literature review

Price competition between OEMs and remanufacturers has been widely discussed in the literature on remanufacturing (Atasu et al., 2008; Debo et al., 2005; Dowlatshahi, 2005; Ferrer and Swaminathan, 2006, 2010; Ferguson and Toktay, 2006; Lieckens et al., 2013; Majumder and Groenevelt, 2001; Seuring, 2013; Wu, 2012a). For example, Majumder and Groenevelt (2001) developed a two-period model where a remanufacturer collects used items that were sold by an OEM in the first period and sells the remanufactured products in the second period, competing with the OEM. Ferrer and Swaminathan (2006, 2010) examined monopoly and duopoly competitions in two-period, multiple-period, and infinite-horizon models, wherein a fraction of the end-of-use items was collected by the OEM at no cost, and the remainder of the end-of-use items were available to the remanufacturer; their work analyzed the equilibrium prices and quantities in price competition between the OEM and the remanufacturer. However, they did not consider the interaction between the OEM and the remanufacturer during the collection of end-of-use items in the recycle market. Furthermore, Atasu et al. (2008) extended the findings of an analysis of price competition between an OEM and a remanufacturer by considering additional attributes of a sales market; specifically, they examined a sales market comprising primary and green segments, where each primary consumer gives a remanufacturer product a lower value than that given to a new product, but a green consumer always prefers to purchase the remanufacturer product. Moreover, they considered that the sales market in the second period might expand or shrink according to product life cycle. Atasu et al. (2008) further specified the effects of these market attributes on the interaction between an OEM and a remanufacturer. Their contribution was mainly concerned with an investigation of pricing interactions of the firms. Wu (2012a) extended the previous studies by incorporating the service competition between a OEM and a remanufacturer, and considered that the new and remanufactured products are sold through a common retailer who determines the sales prices; that is, the manufacturers directly compete on service levels and indirectly compete on prices. The main focus of Wu (2012a) is on the firms' interactions on prices and service levels in the sales market, and thus the recycle market where the remanufacturer can collect the used items to be materials for remanufacturing are not considered. This study differs from the works of Wu (2012a) by examining that the OEM and the remanufacturer directly determine the prices of the owned products, leading to the direct price competition in the sales market; moreover, this study expands the model to a two-period problem, so that the firms' interaction in the recycle market can be examined. Specifically, we consider that the remanufacturer provides the incentive to the recycle market to stimulate the collected quantity of used items to a desired level; meanwhile, the OEM also provide the incentive to deter the remanufacturer to achieve the required quantity of used items for remanufacturing. Hence, a price competition on sales and an incentive competition on collection between the OEM and the remanufacturer emerge. The scenario that the OEM and the remanufacturer simultaneously compete in the sales and recycle markets is not uncommon in practices (e.g., the industry of printer cartridges), and however such a scenario has been rarely investigated in the literature.

We now turn the attention to the studies on remanufacturing that have focused on investigating collection decisions in recycle markets (Heese et al., 2005; Li et al., 2009; Kaya, 2010; Kleber et al., 2011; Pokharel and Liang, 2012; Wei et al., 2014; Hong et al., 2015). Heese et al. (2005) analyzed the profitability of a manufacturer's take-back strategy by considering different competitive environments and found that the manufacturer's choice of a take-back strategy depends on the degree of competition in the recycle market; they also note that a take-back strategy can be treated as a deterrent strategy that prevents rivals from choosing their profitable strategies. However, Heese et al. (2005) did not consider the operational decisions in collection, such that the firms' interaction in collection has not been discussed. Kaya (2010) developed a single period model to examine incentive and production decisions by a manufacturer that uses both new and remanufactured materials in production. His study focused on the performance of various closed-loop systems and on the effectiveness of coordination contracts for those systems, without consideration for the influence of competing remanufacturers. Moreover, Kleber et al. (2011) modeled the interaction between an OEM and several repair stores and identified the decisions and the profitability of a buyback