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Closed-loop supply chain coordination strategy for the remanufacture of patented products under competitive demand

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ABSTRACT

In this study, we consider a closed-loop supply chain (CLSC) system comprising an original manufacturer, third-party remanufacturer, and retailer. In this system, the remanufacturer can only recycle and remanufacture the patented products with patent licensing from the original manufacturer, where newly manufactured and remanufactured products are sold together in the same market at different prices, and the demand for the two types of product is sensitive to their retail prices. First, we establish a leader–follower game model and a joint decision-making model, and we compare the performance of the components of the CLSC, i.e., the collection price, selling prices, and profits. Second, we investigate the contract coordination issues among the three parties in the decentralized case, where we develop a coordinated pricing mechanism that incorporates a revenue-and-sharing contract and two-part tariffs, which can perfectly coordinate the CLSC. Thus, a reasonable range can be identified for the sharing coefficient as well as the agency fees for qualifications. Finally, based some numerical examples, we analyze the impact of the salvage value, substitute ratio, coordination parameters, and other factors on the optimal supply chain performance.

1. Introduction

Due to increasing concerns about the environment and awareness of limited natural resources in recent years, many countries have intensified their legislative efforts regarding the protection of the environment and resources (e.g., [1]), thereby leading to widespread concerns in industry about the collection and remanufacture of used items (e.g., [2–4]). Many enterprises, such as Hewlett-Packard and Kodak, have realized that the collection of used products will facilitate substantial reductions in manufacturing costs as well as elevating their social prestige and economic benefits, thereby creating a closed-loop responsive supply chain in a "resources-production–consumption-renewable resources" looping sequence (e.g., [5]). This process reduces the resources that are required initially as well as the amount of waste produced, which contributes to the coordinated development of the economy and the environment by the manufacturer, with positive effects on the sustainable development of society. Due to reasons related to cost or specific brands, the original manufacturer might not engage in the collection and remanufacture of used items, which is performed by third-party manufacturers. This inevitably leads to competitive threats to the newly manufactured item from the original manufacturer (e.g., [6]). Therefore,

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the original manufacturer may relax this threat to third-party manufacturers by charging patent licensing fees. In addition, the remanufacture of patented products involves licensing issues related to patented technologies, and thus patent licenses are not the only factor that needs to be considered during decision-making by enterprises regarding remanufacture, so all of these issues must be considered in remanufacture supply chain studies.

Pricing decisions related to product sales and recovery are critical during closed-loop supply chain (CLSC) management because they directly affect the supply and demand for products as well as the operational efficiency of CLSC. Therefore, the pricing of CLSC has become an important issue, which has attracted much attention from academic researchers in recent years. Savaskan et al. [7] studied the pricing strategy and channel efficiency of different collection structures in CLSC. However, they assumed that the quantity of returned items is proportionate to the market demand for products, but they did not consider the impact of the collection price on the quantity of returned items, and the collection price was treated as an exogenous variable, which is inconsistent with the reality. El Saadany and Jaber [8] suggested that the quantity of returned items is controlled by the price and quality, and they considered multiple remanufacturing and production cycles. The sales price of used items follows a geometric Brownian motion, so Liang et al. [9] proposed a centralized model for evaluating the acquisition price of used items. Wei and Zhao [10] investigated the optimal wholesale and retail prices of CLSC under competition among retailers using game theory and fuzzy theory. Shi et al. [11] assumed that the selling prices of newly manufactured and remanufactured items are the same while the demand is correlated with price, and they examined two types of product with respect to their production quantity, selling price, and the collection price for used items. However, the market price of a remanufactured item actually always differs from that of the manufactured item and the demands for the two types of product always differs.

Relatively few studies have addressed coordinated pricing for CLSC. Based on game theory, Yi and Yuan [12] studied the CLSC system under a hybrid collection mode, where they analyzed the impact of the hybrid collection mode on pricing and profits. They also employed a two-part tariff to improve the performance of the overall CLSC. However, as the leader of the channel, the manufacturer will obtain all of the excess profits generated after cooperation, whereas the retailer only obtains the profits under decentralized decision-making. Shen and Xiong [13] based their study on an assumption that the manufactured and remanufactured items are homogeneous and that the market demand is a linear function of price. They suggested that the coordination of CLSC can be achieved through the collection and remanufacture of patented products, where they analyzed pricing decision-making by CLSC members, as well as proposing a revenue-and-expense sharing contract to control the sharing ratio through negotiations. However, previous studies have not investigated the situation where newly manufactured and remanufactured items compete in the same market. In addition, CLSC has been studied with respect to the pricing strategy and system performance in different collection channels, modes (e.g., [14,15]), and collection efficiencies (e.g., [16,17]).

Although many studies have investigated pricing and coordination in CLSCs, several research issues have not been addressed, as follows.

- Competition among products.
- Remanufactured and manufactured items with different prices, where the former has a lower price.
- Remanufactured items with salvage value or stockout penalty costs should be considered.
- Revenue-and-expense sharing contracts have not been reported in previous studies. Perfect coordination cannot be achieved with a two-part tariff alone.

By considering the issues mentioned above, a pricing and coordination model for a CLSC system under patent licensing can be established. In the present study, we focus on the following issues.

- We examine the difference in sales between manufactured and remanufactured items, and we study how competition between them in a market can affect the supply chain performance.
- We compare the selling and collection prices for products by each supply chain member, and we determine the performance of the supply chain system and other factors using a leader–follower game and joint decision-making model.
- We explain why a decentralized CLSC cannot be coordinated perfectly by a revenue-and-expense sharing contract.
- We investigate a combined coordinated pricing mechanism for a revenue-and-expense sharing contract and two-part tariffs.
- We study the impacts of the substitute ratio, salvage value, market base, and coordination parameters on supply chain decisions and performance.

2. Problem description

In this study, we consider a CLSC comprising an original manufacturer, third-party remanufacturer, and a retailer. The original manufacturer (referred to as the “manufacturer”) owns the patent rights to the newly manufactured item and takes advantage of its proprietary rights to authorize the work to the third-party remanufacturer as well as providing technical support, staff training, etc., but it does not engage in the collection and remanufacture of used items. There are many similar cases in the manufacturing industry, such as engine remanufacturing and hydraulic pump remanufacturing. The third-party remanufacturer is a manufacturer other than the manufacturer that engages in product collection and remanufacture (the “remanufacturer”). The remanufacturer conducts product collection and remanufactures used items as well as selling the