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# Pricing decisions for short life-cycle product in a closed-loop supply chain with random yield and random demands

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ABSTRACT

Remanufacturing is a product recovery process that transforms a used product into "like-new" condition. It can extend the useful life of a product and help in reducing waste caused by a huge amount of short life-cycle products. Pricing decisions are an important aspect of successful remanufacturing and can secure the profitability of a firm. Remanufacturing for end-of-use products needs to cope with high uncertainties in terms of the quality and quantity of the acquired product returns. Therefore, after inspection, only a fraction of returns can be recovered through remanufacturing operations. This uncertainty in recovery yield influences the decisions impacting acquisition, wholesale, and retail prices. We propose a pricing model that accommodates the random yield effect of product returns on pricing decisions for short life-cycle products in a closed-loop supply chain. The system consists of a retailer, a manufacturer, and a collector of used-products. We apply a sequential decision approach to determine the optimum pricing decision to maximize supply chain profit, according to a pricing game that places the manufacturer as a Stackelberg leader. We demonstrate the effect of changing parameter values on the wholesale and retail prices as well as on the profitability. The results indicate that the profitability of each player and the supply chain as a whole is affected by the quality of the collected used products, the acquisition price, the shortage penalty, and the remanufacturing costs. Interestingly, reducing variance of random yield results in lower profit for the collector even though the other players and the whole supply chain are better off.

## 1. Introduction

Due to recent developments, product life cycles have been becoming shorter and shorter, especially for technology-based products. Coupled with an increasing obsolescence in function and desirability, short life cycle products have created a huge amount of waste. Remanufacturing is a product recovery process that transforms used products into "like-new" condition. It can extend a product's useful life and help in reducing waste. There are three motives for remanufacturing that are often cited in the literature: ethical and moral responsibility, regulation, and profitability [1]. The first motive is relatively weak compared with the others, a fact that was originally noted by Ferrer and Guide [2]. The second motive relies on government regulation, which may not apply to some countries or states. The importance of profitability, however, is supported by several studies [3–6]. There are three key activities in the reverse supply chain, as noted by Guide and Wassenhove [7]. They include the management of product return, issues in remanufacturing operations, and issues in remarketing the remanufactured product. Furthermore, these researchers find that the business perspective, including pricing, which is part of the market development activity, is an area that needs to be explored further.

The pricing decision is an important aspect of a successful remanufacturing project and can secure the profitability of a firm. Atasu et al. [8] find that cannibalization towards new products is not always occurred when remanufactured product is presented. Managers who understand the composition of their markets and use a proper pricing strategy should be able to create additional profit. In a similar manner, Souza [9] notes that there are two implications when manufacturer offers remanufactured product alongside new product i.e. a market expansion effect or a cannibalization effect; hence making the pricing of the two products a critical issue. Therefore, pricing decision is very important in achieving economic advantages from remanufacturing practices.

To sustain the remanufacturing activity, not only the price should be

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right to ensure that the demand is large enough, but also the inputs for the remanufacturing process should be available with sufficient quantity, at acceptable quality, and in an appropriate time. However, unlike the remanufacturing of consumer and business-to-business (B2B) returns, the remanufacturing of end-of-use products needs to cope with high uncertainties in terms of the quality, quantity, and timing of the acquired product returns. After the collected used products are inspected, only a fraction of the returns can be used in a remanufacturing operation. If the collected returns are insufficient or their quality is low, the remanufacturing activity maybe below the economies of scale and leaving significant remanufacturing capacity idle.

There has been discussion on how quality of collected returns may affect the performance of firms in a closed-loop supply chain. As an example, Ford's attempt to enter the automotive recycling industry via Greenleaf LLC resulted in failure due to problems in the quality of the collected returns. A manager at Ford, James L. Richardson, stated that the value of the materials they bought was lower than the value for which they actually paid [10]. Higher quality returns can reduce remanufacturing cost, consume less production capacity and have higher salvage value [9]. Random yield of product returns also influences the decisions in acquisition price and selling price [10]. It is not quite obvious however, how the quality of collected returns affect the behavior of closed-loop supply chain players in a more complex problem setting, especially when more parties are involved and the products handled are short life in nature.

This paper accommodates the effect of the random recovery yield of product returns on pricing decisions for short life-cycle products in a closed-loop supply chain. We consider a closed-loop supply chain that consists of a manufacturer, a retailer, and a collector in a pricing game under Stackelberg leadership with manufacturer as the leader. The collector obtains used products (cores) from the customers and then sells them to the manufacturer with a certain transfer price. A random recovery yield variable is introduced, which represents the fraction of returns that are remanufacturable. Cores not acceptable for remanufacturing would be sold by the collector to another party with a certain salvage value. We also introduce a shortage penalty as an attempt to entice the collector to obtain sufficient recoverable returns. Thus, when making decisions on the quantity of cores to be collected, the collector needs to consider the transfer price, the recovery yield parameters, the shortage penalty, as well as the salvage value. The purpose of this study is to determine the optimum wholesale price, retail price, and acquisition price and the relevant order or production quantities so that the supply chain's profits can be maximized. In addition we also aim to explore how the change in parameter values affect the decisions along the supply chain and how these decisions subsequently affect their profitability.

## 2. Literature review

The importance of pricing strategy in a closed-loop supply chain that concerns remanufacturing has been previously explored in several studies [7,8,11]. The results from these studies received positive responses, which can be ascertained through the ever-increasing number of studies on pricing decisions in remanufacturing practices, whether from the perspective of one member or several key members in the supply chain.

There are numerous studies on pricing remanufactured products for profit maximization. For instance, the studies by Ferrer and Swaminathan [12], Atasu et al. [5], and Ovchinnikov [13]. Gan et al. [14] search for the optimal price and quantity under a deterministic setting, focus on pricing decisions in a closed-loop supply chain involving manufacturer, retailer and collector of used products (cores). They consider a monopolist of a single item with no constraint on the quantity of remanufacturable cores throughout the selling horizon. Demand functions are deterministic and linear in price; and they represent the short life-cycle patterns along the entire phases of product life-cycle. The objective of the proposed model is to find the optimal wholesale and retail prices for both new and remanufactured products; and the optimal acquisition and transfer prices. Recently, Gan et al. [15] propose a pricing decision model for a closed-loop supply chain involving manufacturer, retailer, and collector, where the remanufactured products are sold via separate sales channel. Furthermore, a problem in pricing and warranty level decisions for new and remanufactured products are also studied [16]. However, the abovementioned studies have not yet considered uncertainty in the recovery-yield while the returned cores are not always economically or technically feasible to remanufacture. Furthermore, they have not considered random demand, while the product life-cycle is short with an obsolescence effect that would increase the demand's uncertainty.

In many cases, remanufacturing is performed by the manufacturer, and so a hybrid system is applied. Pricing models in this setting have been discussed by several authors. Ferrer and Swaminathan [12] study a problem where a manufacturer produces new products during the first period and offers both new and remanufactured products during subsequent periods by utilizing the returned number of used products. The new and remanufactured products are not differentiated but rather are sold in the same market at the same price. Moreover, the proposed models are developed for 2-periods monopoly and duopoly, more than two periods, and the infinite planning horizon. The models aim to find the optimum quantities and prices of new and remanufactured products that will maximize profit. Extending their work, Ferrer and Swaminathan [17] propose a similar scenario, but they differentiated between the prices of new and remanufactured products. Atasu et al. [5] recognize three drivers from demand-related aspects which are competing with the Original Equipment Manufacturer (OEM) directly, having green segment as a the potential market from, and utilizing the speed of market growth. The results confirmed that these three factors have strong interactions and significant impacts on remanufacturing decisions. Furthermore, they manage to show that remanufacturing can be an effective marketing strategy and not merely a cost-saving strategy or an approach to achieving compliance with environmental regulations. In the competition with an OEM's strong brand image, the analysis shows that a remanufacturing strategy could draw more customers. Ovchinnikov [13] proposes a model for finding the optimal profit-maximizing prices and quantities of remanufactured products when both new and remanufactured product are sold side by side. Customer switching behavior was also studied to understand their choices behind buying new or remanufactured products and to identify how large is the fraction of customers who switch from buying new products to remanufactured ones. Shi et al. [18] propose a model to determine the price and quantities of new and remanufactured product, and the used products' acquisition price, which would maximize the total profit of the supply chain. In this model, the price of remanufactured products is not differentiated from new products, and both are sold in the same market. Furthermore, demand and return are both stochastic and price-sensitive. The analysis shows that for a small market size, the optimal strategy is pure remanufacturing. However, for a large market, the best strategy is mixed manufacturing/remanufacturing. The effect of demand uncertainty significantly impacts the production plan and the selling price of new products. Instead, the uncertainty of return affects not only the remanufacturing plan but also the manufacturing plan of new products. Chen and Chang [19] develop a dynamic pricing model for new and remanufactured products under a constrained supply of used products. The model is developed with a static environment as the benchmark and a two-period and multi-period setting over the product life cycle, to determine the optimum prices for maximizing profit. Although the products are differentiated, they are partially substitutable. Another study by Xiong et al. [20] takes into account the lost sales and uncertain quality of used products in developing a pricing model for core product acquisition for remanufacturing companies. In this model, the demand is stochastic and the objective of the model is cost minimization over finite and infinite horizons.

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