Investigation on Pricing Decisions of Remanufactured Products and Profit of Supply Chain

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Keywords: Remanufacturing, Pricing, Closed-loop Supply Chain.

Abstract: This study investigates the closed-loop supply chain (CLSC) with respect to hybrid manufacturing/remanufacturing systems. In this study, a hybrid manufacturing/remanufacturing model is designed that encompasses the simultaneous production of new manufactured products and remanufactured products; this model is used to investigate the profitability of a hybrid manufacturing/remanufacturing system. The impact on the demand for new products (cannibalization effect) caused by selling remanufactured products is a concern among companies with respect to promoting the CLSC. The purpose of this study is to examine the effects on the profits obtained by a company. Numerical experiments are conducted to confirm the profitability of a hybrid manufacturing/remanufacturing system; the relationship between the demand for manufactured products and that for re-manufactured products is also investigated. This study proposes a pricing model for remanufactured products by considering consumers' willingness to pay. The analytical results indicate that the cannibalization effect was suppressed by considering these, and it is clear that remanufactured products increase company profits.

1 INTRODUCTION

Japan has undergone a protracted period of economic growth that is based on mass production, mass consumption, and mass disposal. As a result, Japan is facing environmental and resource-depletion problems. Recently, companies have taken action to assume corporate social responsibility and address environmental problems, by manufacturing while bearing in mind the environment and resource consumption. A closed-loop supply chain (CLSC) system is one approach taken to support such efforts.

Various methodologies and examples of supply chains have recently been reported. An efficient supply of products and services is required, owing to the shift from a producer-led economy to a consumer-led one; however, there is a dearth of quantitative analyses on the profit potentials of companies that have manufacturing/remanufacturing systems. Net losses deriving from collecting, reusing, and recycling used products can create enterprise-wide problems; therefore, when employing CLSC systems, it is critical to ensure that there are net gains.

The hybrid model proposed in this study encompasses both manufacturing and re-manufacturing. Moreover, scenarios with variable ratios for collecting, remanufacturing, and refurbishing are used throughout the proposed model. We also undertake numerical experiments to confirm the profitability of hybrid manufacturing/remanufacturing systems.

Additionally, we consider the relationship between the demand for manufactured products and that for remanufactured products. If a company considers used products to be new products, and sells only new products, it is not necessary to consider the relationship between these two types of demand. However, if the company sells remanufactured products separately from new products, then this hybrid manufacturing/remanufacturing model can be used to investigate both the cannibalization effect and market expansion. These two effects are important to the development of an effective CLSC, and so we consider them in the context of the proposed hybrid manufacturing/remanufacturing model.

* https:// www.sd.tmu.ac.jp/RDstaff/data/ka/641.html

Kainuma, Y.
Investigation on Pricing Decisions of Remanufactured Products and Profit of Supply Chain.
DOI: 10.5220/0007313102530257
In *Proceedings of the 8th International Conference on Operations Research and Enterprise Systems (ICORES 2019)*, pages 253-257
ISBN: 978-989-758-352-0

2 LITERATURE REVIEW

We reviewed many studies to obtain a comprehensive understanding of hybrid manufacturing/remanufacturing systems. Mitra (2016) considers a duopoly environment with two manufacturers in direct competition, both of which are selling their respective new products on the primary market. Specifically, he considers whether one manufacturer gains a competitive advantage over the other when the other manufacturer decides to remanufacture and sell remanufactured products on the price-sensitive secondary market. However, Mitra does not undertake a quantitative assessment in relation to the cannibalization effect.

Nanasawa and Kainuma (2017) quantitatively evaluate the impact of the cannibalization effect on profits in a hybrid manufacturing/remanufacturing system. By considering the selling price and the timing of the introduction of remanufactured products, they elucidate the profitability of remanufactured product sales.

Gan et al. (2017) proposed a pricing model developed for short life cycle products in closed loop supply chain consisting of manufacturer, retailer, and collector. They showed that implementing separate channels can improve the overall supply chain benefit compared to single channel approach.

Souza (2012) shows that remanufactured products have two effects on consumer demand—namely, market expansion and cannibalization. Generally, the cannibalization effect is thought to reduce profits as new-product demand decreases. However, Atasu et al. (2010) discuss the theory that remanufactured product sales can reduce or eliminate new-product sales, and that the sale of remanufactured products can make it possible to reach additional market segments. Furthermore, Guide and Li (2010) assert that examinations of the cannibalization effect are important to CLSC development.

During the literature review, we found there to be many studies on the cannibalization effect; however, only a few are quantitative evaluations.

3 MODEL

A hybrid manufacturing/remanufacturing system is modelled and analysed using the proposed model. Fig.ure1 shows that the CLSC system consists of three members - namely, a manufacturer, a products reach their end of use and become the objects of used-product collection. The used products are acquired by

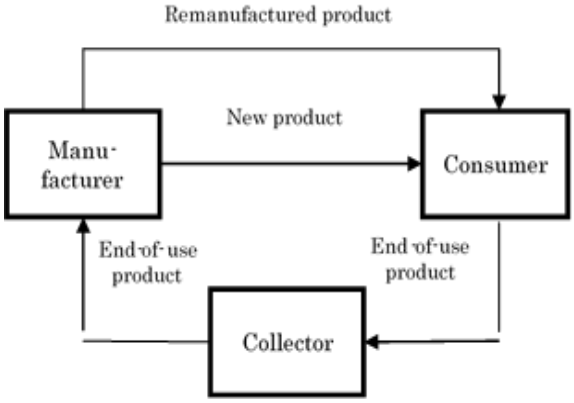

Figure 1: A closed-loop supply chain system.

the collector. (It is assumed that the consumer, and a collector. The closed loop is initiated by a manufacturer who makes new products for consumers. After a certain period, the same collector gathers only those used products that meet the quality level demanded by the remanufacturing process.) Therefore, all of the collected returns are transferred to the manufacturer as inputs for the remanufacturing process.

We divide consumers into two segments. One comprises primary consumers who are conscious of novelty. They basically purchase new products, but there is the possibility of buying remanufactured products at lower prices. The other comprises 'green' consumers aware of functionality. They purchase remanufactured products only because (we assume) the price of a new product is higher than that which they estimate.Before estimating the expected profit, we introduce the following notations and parameters, which are used in Equations (1)–(8).

Notations

Π	Total expected profit of entire supply chain
Π_M	Manufacturer's total expected profit
Π_C	Collector's total expected profit
D_n	Demand for new product
D_r	Demand for remanufactured product

Parameters

p_n	Selling price of new products
p_r	Selling price of remanufactured products
p_c	Purchase price of end-of-use products
p_f	Selling price of end-of-use products

p_m	Maximum price as the upper limit
c_{rw}	Unit raw material cost for producing new product
c_m	Unit manufacturing cost for producing new product
c_r	Unit remanufacturing cost for producing remanufactured product
c	Unit collecting cost
d_n	Cumulative potential demand for new product
d_r	Cumulative potential demand for remanufactured product
β_1	Scaling factor of remanufactured products for primary consumers
β_2	Scaling factor of remanufactured products for green consumers
δ	Discount ratio
φ	Constant
θ	Exponential constant

3.1 Expected Profit

This study assumes that the demand for remanufactured products differs from that for new products, and that the new product price is different from that of the remanufactured product price. The total expected profit is derived via Equation (1). Furthermore, Equation (2) derives the total expected profit of the manufacturer, while Equation (3) derives the total expected profit of the collector.

$$\Pi = \Pi_M + \Pi_C \tag{1}$$

$$\Pi_M = D_n\left(p_n - c_{rw} - c_m\right) + D_r\left(p_r - p_f - c_r\right) \tag{2}$$

$$\Pi_C = \varphi p_c^{\theta} D_n \left(p_f - p_c - c\right) \tag{3}$$

3.2 Demand

We analyse the relationship between the demand for new manufactured products (Equation (4)) and that for remanufactured products (Equation (5)). Souza (2012) criticizes the CLSC approach and instead focuses on the strategic problem of network design, as well as the tactical problem of use and disposal. Souza claims that the remanufacturing of products has two effects on consumer demand. The first of these is market expansion. Souza suggests that the sale of remanufactured products drives consumer expansion, given price differences between new and remanufactured products. The second effect is cannibalization, where consumers who had originally intended to purchase new products decide instead to purchase remanufactured products, given their lower price.

$$D_n = \begin{cases} \dfrac{d_{12}}{p_m}\left[p_m - \dfrac{p_n - p_r}{1-\beta_1}\right] & p_r \le \beta_1 p_n \\ \dfrac{d_{12}}{p_m}\left[p_m - p_n\right] & \beta_1 p_n \le p_r \le \beta_2 p_n \\ 0 & p_r \ge \beta_2 p_n \end{cases} \tag{4}$$

$$D_r = \begin{cases} \dfrac{d_{34}}{p_m}\left[p_m - \dfrac{p_r}{\beta_2}\right] + \dfrac{d_{12}}{p_m}\left[\dfrac{p_n - p_r}{1-\beta_1} - \dfrac{p_r}{\beta_1}\right] & p_r \le \beta_1 p_n \\ \dfrac{d_{34}}{p_m}\left[p_m - \dfrac{p_r}{\beta_2}\right] & \beta_1 p_n \le p_r \le \beta_2 p_n \\ 0 & p_r \ge \beta_2 p_n \end{cases} \tag{5}$$

4 NUMERICAL EXPERIMENT AND RESULTS

We conducted numerical experiments by using the proposed model. Optimization is carried out under a sequential Stackelberg game, with the manufacturer as the leader. The objective of the pricing model is to determine the optimal prices that maximize profits. Here, the demand function varies depending on the price of the remanufactured products, and so numerical experiments are carried out separately in the following cases.

Condition (a): $p_r \le \beta_1 p_n$

Condition (b): $\beta_1 p_n \le p_r \le \beta_2 p_n$

Since the purchase price of end-of-use products does not fluctuate under either condition, it is indicated by Equation (6). The selling price of end-of-use products in conditions (a) and (b) is given by Equations (7) and (8), respectively.

$$p_c = \frac{(p_f - c)\cdot\theta}{\theta+1} \tag{6}$$

$$p_f = \left[\frac{d_{34}\left(p_m - \frac{p_r}{\beta_2}\right) + d_{12}\left(\frac{p_n - p_r}{1-\beta_1} - \frac{p_r}{\beta_1}\right)}{\varphi\, d_{12}\left(p_m - \frac{p_n - p_r}{1-\beta_1}\right)}\right]^{\frac{1}{\theta}} \cdot\frac{\theta+1}{\theta} + c \tag{7}$$

$$p_f = \left[\frac{d_{34}\left(p_m - \frac{p_r}{\beta_2}\right)}{\varphi\, d_{12}\left(p_m - p_n\right)}\right]^{\frac{1}{\theta}} \cdot\frac{\theta+1}{\theta} + c \tag{8}$$

Table 1 shows the prices of new and remanufactured products when the total expected profit is maximized. From this table, we can see that the overall profit is significantly higher under condition (a) than under condition (b). This is thought to be due to an increase in profits as a result of further increasing the demand for remanufactured products, while demand for new products has decreased due to the evaluation of remanufactured products.

In addition, we found that benefits accruing from the overall supply chain are increased if the selling price is reduced when comparing the selling price of the remanufactured product (i.e. the largest profit of the manufacturer) and the selling price of the remanufactured product (i.e. the maximum profit of the entire supply chain). This is due to an increase in the profit of the collector as the demand for remanufactured products increases and the number of used products increases, both as a result of reducing the selling price of remanufactured products; this in turn results in an increase in the overall supply chain.

Table 1: Prices of new and remanufactured products when total expected profit is maximized (in Japanese yen).

	Condition (a)		Condition (b)	
	Max Π_M	Max Π	Max Π_M	Max Π
p_n	8,300	8,300	8,200	8,200
p_r	5,644	5,561	4,756	4,674
Π_M	2,849,619,740	2,849,231,360	2,690,604,111	2,690,599,220
Π_C	11,106,216	17,075,940	2,830,719	2,966,877
Π	2,860,725,956	2,866,307,299	2,693,434,829	2,693,566,097

Figure 2 shows the relationships among the total expected profit for the overall supply chain, the selling price of new product, and the discount ratio. We found that there were cases in which the total expected profit of the overall supply chain had decreased. This is because the demand for the new products will decrease and the collection volume of end-of-use products will decrease if the selling price of new products is too high. It is considered that the

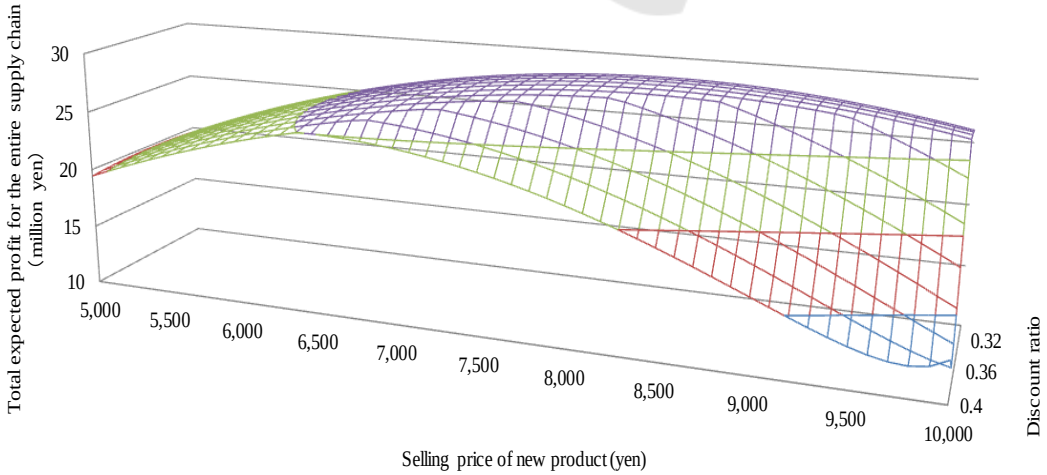

Figure 2: Relationships among total expected profit for the entire supply chain, the selling price of new product, and discount ratio.

profit of the overall supply chain will decrease, because while there is still potential demand for remanufactured products, they cannot be sold if the collection volume of end-of-use products decreases.

5 CONCLUSIONS

In this study, we proposed a pricing decision model for remanufactured products while considering game theory. We executed numerical experiments using a hybrid manufacturing–remanufacturing model. The model was evaluated using a number of different parameters. We were able to evaluate profitability by examining trends in expected profits that derive from the selling prices of new products and remanufactured products. The results indicate that a hybrid manufacturing–remanufacturing system is more profitable. Furthermore, the demand model used in this study clearly shows the relationship between the demand for new manufactured products and the demand for remanufactured products. Therefore, by studying the appropriate priced of new and remanufactured products, companies should be able to successfully structure their remanufacturing businesses so as to mitigate profit reductions incurred by the cannibalization effect. In addition, we found that is essential to consider not only a manufacturer's own profit, but also pricing while bearing in mind the optimum of the overall supply chain.

Finally, we plan to extend our research by considering comparisons among products with different cost structures, opportunity losses, and penalties, among other characteristics.

ACKNOWLEDGEMENTS

This research was partially supported by a grant-in-aid for scientific research (No. 15K01219) from the Japan Society for the Promotion of Science (JSPS).

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