# Profitability of Hybrid Manufacturing/remanufacturing System in Closed Loop Supply Chain

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**Abstract.** In this study, we investigate the closed-loop supply chain (CLSC) with respect to hybrid manufacturing/remanufacturing system. A hybrid manufacturing/remanufacturing model, encompassing the simultaneous production of manufactured new products and remanufactured products, is designed to investigate the profitability of the hybrid manufacturing/remanufacturing system. Two-stage scenarios with varying collection ratios, remanufacturing ratios, and refurbishing ratios are made and analyzed using the proposed model. In the first stage, only new products are sold and the end-of-use products are collected. In the second stage, both new and remanufactured products are sold at the same time and the end-of-use products are collected simultaneously. Numerical experiments are conducted in order to confirm the profitability of the hybrid manufacturing/remanufacturing system. The relationship between the demand for manufactured products and remanufactured products is also investigated. In particular, we analyze the price elasticity relationship between a change in the price and a change in the demand for remanufactured products. From analyses results, it can be concluded that the proposed hybrid manufacturing/remanufacturing model is more accurate than other models that neglect remanufacturing in confirming that the hybrid manufacturing/remanufacturing system is more profitable.

**Keywords:** Closed-loop supply chain, hybrid manufacturing/remanufacturing, cannibalization effect, profitability

## 1. INTRODUCTION

Japan has undergone a long period of economic growth based on mass production, mass consumption, and mass disposal. As a result, Japan is facing environmental problems and resource depletion. Recently, companies have taken action to assume corporate social responsibility and address environmental problems by manufacturing with consideration for the environment and resource consumption. A closed-loop supply chain (CLSC) system is one approach used to accomplish this effort.

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 economy; however, there are not many quantitative analyses on the profit potentials of companies having manufacturing/remanufacturing systems. A net loss from collecting, reusing, and recycling used products can create an enterprise-wide problem. Therefore, it is critical to ensure that there is a net gain when employing CLSC systems.

The proposed hybrid model in this study encompasses both manufacturing and remanufacturing. Moreover, scenarios with variable ratios for collecting, remanufacturing, and refurbishing are used throughout the proposed model. Numerical experiments are employed to confirm the profitability of the hybrid manufacturing/remanufacturing system.

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

## 2. LITERATURE REVIEW

We reviewed many studies in order to gain a comprehensive understanding of hybrid manufacturing/remanufacturing systems. Mitra (2015) considered a duopoly environment with two manufacturers in direct competition selling their respective new products on the primary market. Specifically, he considered whether one manufacturer gained a competitive advantage over the other when the other manufacturer decided to remanufacture and sell remanufactured products on the price-sensitive secondary market. However, Mitra did not study a quantitative assessment in relation to the cannibalization effect.

In this study, we use the Bass model (Bass, 1969) to express the product life cycle curve. The Bass model consists of two models proposed by Fourt and Woodlock (1960) and Mansfield (1961). Bass proposed a model that considered the spread speed of new products using the innovator/imitator characteristic. Oshita and Kainuma (2009) proposed a cascade reuse model and optimal ordering policy for new and reused parts in hybrid manufacturing/remanufacturing systems that are based on the Bass model.

In addition, we examine the cannibalization effect based on the Bass model. The cannibalization effect is related to product life cycle. Souza (2012) shows that remanufactured products have two effects on consumer demand: market expansion and cannibalization. Generally, the cannibalization effect is thought to decrease profit as new product demand decreases. However, Atasu and Wassenhove (2010) discussed the theory that remanufactured product sales can reduce or eliminate new product sales, and that remanufactured products can make it possible to reach additional market segments. Furthermore, Guide and Li (2010) asserted that examination of the cannibalization effect is important in developing a CLSC.

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

## 3. THE MODEL

The following notations and parameters are used in Equations (1) through (8):

*Notations*

| | |
|---|---|
| $\Pi$ | Total expected profit |
| $\Pi_1$ | Expected profit in first stage |
| $\Pi_2$ | Expected profit in second stage |
| $t$ | Time period, $t = 1, 2, \ldots T$ |
| $f(t)$ | Probability density function of new product |
| $F(t)$ | Distribution function of new product |
| $V(t)$ | Number of purchased new products |
| $g(t)$ | Probability density function of remanufactured product |
| $Y(t)$ | Number of purchased remanufactured products |
| $S(t)$ | Characterizes when both new and remanufactured products are sold at the same time |

*Parameters*

| | |
|---|---|
| $d_{1n}^t$ | Demand for new products at period $t$ in first stage |
| $d_{2n}^t$ | Demand for new products at period $t$ in second stage |
| $d_{2r}^t$ | Demand for remanufactured products at period $t$ in second stage |
| $p_{1n}^t$ | Price of new products at period $t$ in first stage |
| $p_{2n}^t$ | Price of new products at period $t$ in second stage |
| $p_{2r}^t$ | Price of remanufactured products at period $t$ in second stage |
| $c_{1n}^t$ | Cost of new products at period $t$ in first stage |
| $c_{2n}^t$ | Cost of new products at period $t$ in second stage |
| $c_{2r}^t$ | Cost of remanufactured products at period $t$ in second stage |
| $\Delta t$ | Introduction timing of remanufactured products |
| $\delta_r$ | Discount ratio |
| $\theta$ | Alternate degrees for remanufacturing products for consumers |
| $\gamma$ | Remanufactured critical ratio |
| $\phi$ | Decreasing ratio |
| $p$ | Coefficient of innovation |
| $q$ | Coefficient of imitation |
| $M$ | Potential market scale of new products |
| $m$ | Potential market scale of remanufactured products |
| $t^*$ | Intersection of $f(t)$ and $g(t)$ |
| $\varepsilon$ | Price elasticity |
| $C_0$ | Integration constant |

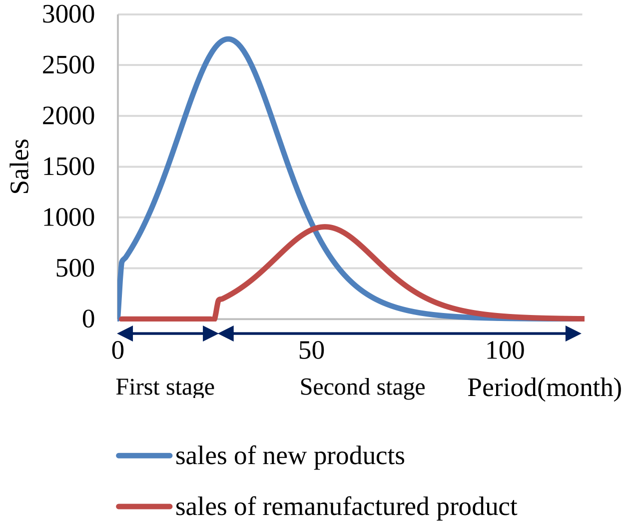


Figure 1: Relationship between the sales of new and remanufactured products and the concept of the stages.

The hybrid manufacturing/remanufacturing system is modeled and analyzed using the proposed model in two stages. In the first stage, only new products are sold and the end-of-use products are collected. In the second stage, both new and remanufactured products are sold at the same time and the end-of-use products are collected simultaneously. Figure 1 shows the relationship of sales of new and remanufactured products and the concept of the stages.

### 3.1 Expected Profit

Before formulating the expected profit, the following assumptions and notations are introduced. This study assumes that the demand for remanufactured products differs from the demand for new products, and that the new product price is different from the remanufactured product price. The expected profit is derived through the following equation:

$$\begin{aligned}\Pi &= \Pi_1 + \Pi_2 \\ &= \sum_{t=0}^{\Delta t}\left(p_{1n}^t - c_{1n}^t\right)\times d_{1n}^t \\ &+ \sum_{t=\Delta t}^{T}\left[\left(p_{2n}^t - c_{2n}^t\right)\times d_{2n}^t + \left(p_{2r}^t - c_{2r}^t\right)\times d_{2r}^t\right]\end{aligned} \qquad (1)$$

### 3.2 Demand

The relationship between the demand for newly manufactured products and remanufactured products is analyzed. Souza (2012) criticized the CLSC approach, and instead focused on the strategic problem of network design and the tactical problem of use and disposal. The Souza study claimed that remanufacturing products has two effects on consumer demand, the first being market expansion. The study suggested that the sale of remanufactured products drives consumer expansion due to price differences between new and remanufactured products. The second effect is cannibalization, where consumers who intend to purchase new products switch over to purchase remanufactured products because of their lower price. The Bass model accounts for the spread speed of a new product. The literature is used as a reference in this study. Equations (2), (3), and (4) are used to quantify demand ( $\Delta t$ is the introduction timing of remanufactured products). Equation (5) characterizes the period when both new and remanufactured products are sold at the same time ($t^*$ is the intersection of $f(t)$ and $g(t)$).

$$\frac{f(t)}{1-F(t)} = p + qF(t) \qquad (2)$$

$$f(t) = \frac{p(p+q)^2 e^{-(p+q)t}}{\left(p + qe^{-(p+q)t}\right)^2} \qquad (t>0) \qquad (3)$$

$$g(t) = \gamma\frac{p(p+q)^2 e^{-(p+q)(t-\Delta t)}}{\left(p + qe^{-(p+q)(t-\Delta t)}\right)^2} \qquad (\Delta t < t) \qquad (4)$$

$$S(t) = \int_{\Delta t}^{t^*} g(t)dt + \int_{t^*}^{T} f(t)dt \qquad (5)$$

### 3.3 Price Elasticity

The relationship between the demand and the price for remanufactured products is analyzed. If the price of remanufactured products is decreased, the demand for those products increases. Conversely, if the price of remanufactured products is increased, the demand for those products decreases. Next, we considered price elasticity represented by Equations (6) and (7). Figure 2 shows the relationship between demand and price of remanufactured products.

$$\varepsilon = \frac{\Delta demand \,/\, demand}{\Delta price \,/\, price} \qquad (6)$$

$$demand = C_0\, price^{-\varepsilon} \qquad (7)$$

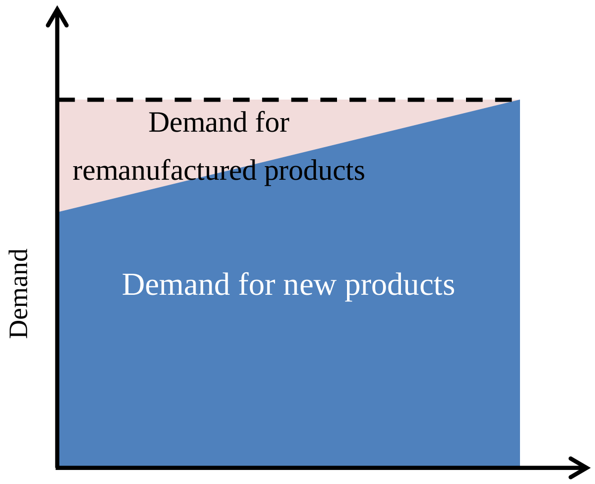


Figure 2: Relationship between demand and price of remanufactured products.

## 4. NUMERICAL EXPERIMENT AND RESULTS

Numerical experiments using the proposed model were conducted. Recently, printers, automobiles, and other products have been manufactured with consideration for the environment and resource consumption. Toner cartridges were used as the example product for the numerical experiments in this study because they are considered to have great potential for component recycling. In general, new products begin to be sold as remanufactured products in approximately a year. Therefore, in this study we examined the introduction timing of remanufactured products in a range from 12 months to 48 months. The potential market scale of new products was 100,000 units. In addition, we considered the decreasing ratio in the demand for remanufactured products when we changed the introduction timing of remanufactured products. The decreasing ratio is represented by Equation (8). We proposed two scenarios: scenario 1 does not include price elasticity; scenario 2 includes price elasticity.

$$m^{\Delta t} = \gamma M \times e^{-\phi(\Delta t - 12)} \quad (8)$$

### 4.1 Parameters and Scenario 1

In the experiment, it was assumed that the price of a new toner cartridge was 60,000 yens per unit. The cost to manufacture was 15,000 yens per unit, and the cost to remanufacture was 7,500 yens per unit. The proposed model was used to simulate scenarios that varied the discount ratio, the remanufactured critical ratio, and the alternate degrees for remanufacturing the product for consumers. The discount ratio is defined as a ratio of remanufactured product price to new product price, four levels. The remanufactured critical ratio is defined as a ratio that summarizes all proportions, such as the return ratio, discard ratio, yield ratio, five levels. Alternate degree is defined as a ratio that characterizes how consumers purchase remanufactured products when both new and remanufactured products are sold at the same time, six levels). Subsequent numerical experiments were executed to confirm the profitability of the hybrid manufacturing/remanufacturing system.

### 4.2 Numerical Experiment Results 1

Figure 3 shows the relationship between alternate degrees for remanufacturing products of consumers and total expected profit. It is evident that total expected profit decreases when alternate degrees for remanufacturing products for consumers increase. We found that in some cases it becomes more profitable when only new products were sold. Figure 4 shows the relationship between introduction timing of remanufactured products and total expected profit. There is a little more profit than when only new products are sold in introduction timing of remanufactured products.

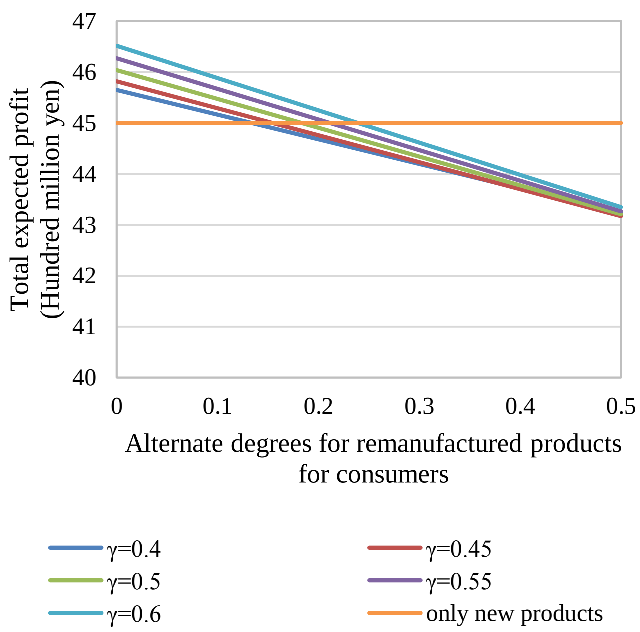


Figure 3: Relationship between alternate degrees for remanufactured products for consumers and total expected profit.

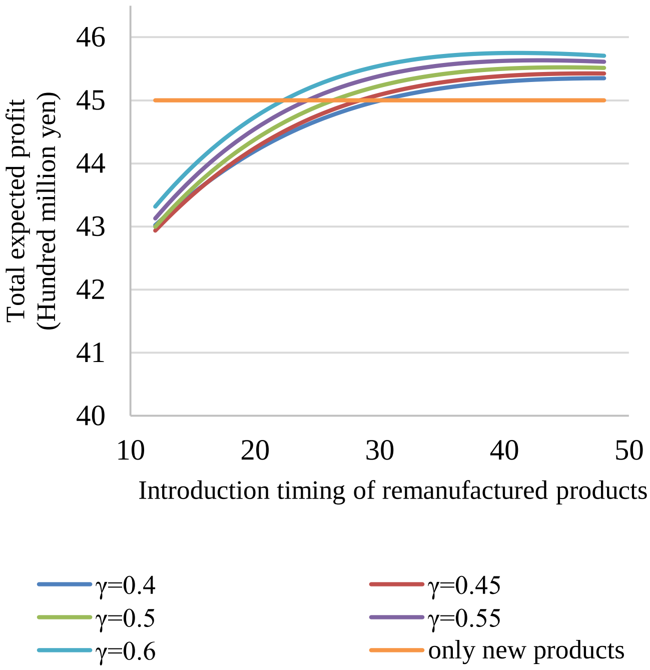


Figure 4: Relationship between introduction timing of remanufactured products and total expected profit.

### 4.3 Parameters and Scenario 2

In the experiment, it was assumed that the parameters in scenario 1 were the same as those in scenario 1, except for the price of remanufactured products. The price of remanufactured products made them fluctuate between from 30% to 70% of new products. Scenarios that varied the remanufactured critical ratio (two levels) were simulated with the proposed model. Subsequent numerical experiments were executed to confirm the profitability of the hybrid manufacturing/remanufacturing system.

### 4.4 Numerical Experiment Results 2

Figure 5 shows the relationships among introduction timing of remanufactured products, the price of remanufactured products, and total expected profit. We found the case to be that it was more profitable than when only new products were sold owing to the fact that the number of consumers who bought remanufactured products increased when the price of remanufactured products was too low. Furthermore, it did not become more profitable when introduction timing of remanufactured products was too early, due to market expansion and cannibalization effects.

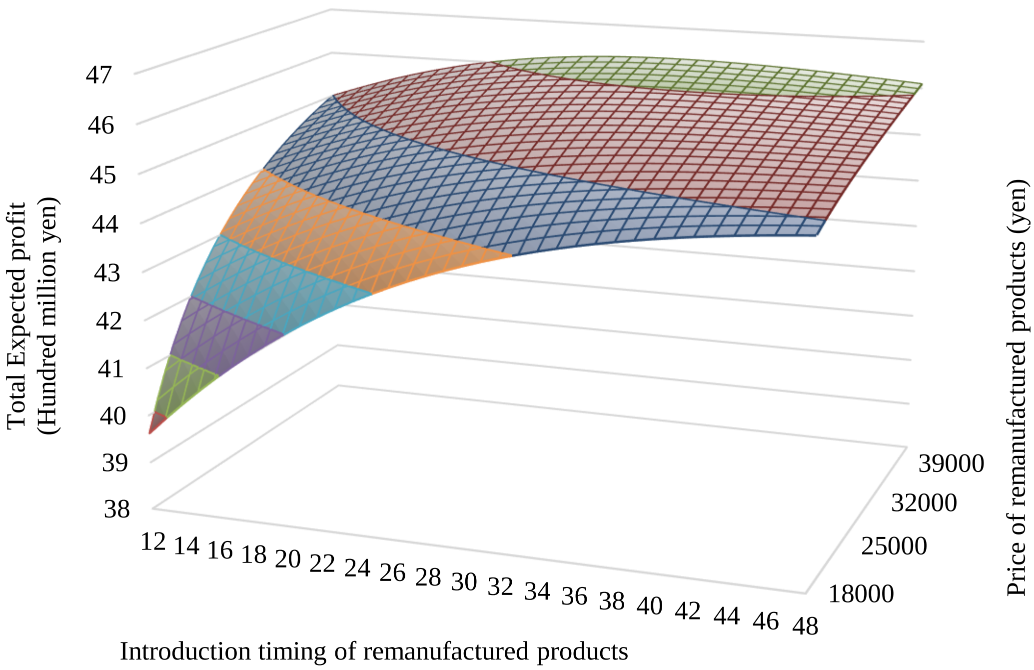


Figure 5: Relationship among introduction timing of remanufactured products, the price of remanufactured products, and total expected profit.

## 5. CONCLUSION

In this study, we utilized a hybrid manufacturing/remanufacturing model encompassing the introduction timing of remanufactured products in two stages: new manufacturing and remanufacturing. Scenario simulations and numerical experiments using toner cartridges as the example product were executed using the hybrid manufacturing/remanufacturing model. The model was evaluated using a number of different parameters. The results indicate that the hybrid manufacturing/remanufacturing system is more profitable. Furthermore, the demand model used in this study clearly shows the relationship between the demand for newly manufactured products and the demand for remanufactured products. Therefore, by studying the appropriate introduction timing of the remanufactured product and the price of remanufactured products, companies should be able to successfully structure remanufacturing businesses to mitigate profit reduction caused by the cannibalization effect.

Lastly, we plan to continue research by considering characteristics of product quality, such as product life cycle.


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## REFERENCES


Atasu, A., Guide, V.D.R., Van Wassenhove, L.N. (2010). So what if remanufacturing cannibalizes my new product sales?. *California management review*, 52(2), 1-21

Bass, F.M. (1969). A new product growth model for consumer durables. *Management Science*, 15(5), 215-227

Fourt, L.A., Woodlock, J.W. (1960). Early prediction of market success for grocery products. *Journal of Marking*, 25(2), 31-38

Guide, V.D.R., Li, J. (2010). The potential for cannibalization of new products sales by remanufactured products. *Decision Sciences*, 41(3), 547-572

Mansfield, E. (1961). Technical change and the rate of imitation. *Econometric Society*, 29(4), 741-766

Mitra, S. (2015). Models to explore remanufacturing as a competitive strategy under duopoly. *Omega*, 59, 1-13

Oshita, Y., Kainuma, Y. (2009). Remanufacturing operation in closed-loop supply Chain. *Proceedings of the 6th International Symposium on Environmentally Conscious Design and Inverse Manufacturing*, CD-ROM

Souza, G.C. (2012). Closed-loop supply chains: A critical review, and future research. *Decision Sciences*, 44(1), 7-38