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Pricing Decision for New and Remanufactured Product in a Closed-loop Supply Chain with Separate Sales-channel

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Abstract

Remanufacturing is one of the recovery processes that transforms a used product into a “like-new” product, and usually comes with similar warranty to the new product. Many manufacturers have concerns that remanufacturing might cannibalize the sales of the new product. Recent development shows an increasing trend in selling products through non-traditional channels such as manufacturer’s direct channel or e-channel. We develop a pricing decision model for short life-cycle product in a closed-loop supply chain that consists of manufacturer, retailer, and collector. New product is sold via traditional retail store and remanufactured product is sold via manufacturer’s direct channel, such as factory outlet. We introduce two scaling factors; the first represents customer’s acceptance towards buying remanufactured product, and the second represents customer’s preference to buy remanufactured product via direct channel. The results show that implementing separate channel can improve the total supply chain’s profit compared to single-channel approach. We also find that both scaling factors influence pricing decisions and the profits of the supply chain members.

Keywords: pricing; remanufacturing; sales-channel; short life-cycle products.

1. Introduction

Most of the pricing models for new and remanufactured products use single sales channel, where both products are sold in the same channel, and typically in a retail store. However, recent development shows that there is an increasing trend in selling products through non-traditional channels such as manufacturer’s direct channel (for example factory outlet or warehouse stores), and e-channel or online stores. Dell computer sells its remanufactured product via online channel called “Dell Outlet” [1], while offers new product via both retail stores and online market. Similar to Dell computer, Hewlett-Packard/HP also sells the remanufactured computers in HP’s online outlet store, and customer cannot buy it at retail store such as Best Buy, as revealed by [2]. He argues that OEM usually sells remanufactured product in different sales channel from new product to reduce the effect of cannibalization. Atasu et al. suggest that pricing strategy for new and remanufactured product should focus on market segmentation, where they recognized two main segments namely newness-conscious segment and functionality-oriented segment [3]. The latter would be a potential market for remanufactured product. Moreover, Atasu et al. claim that focusing remanufactured product sales to functionality-oriented segment can improve the competition advantage against no-brand low cost product that is targeting customers with lower the willingness-to-pay. Therefore, it is important to explore the effect of offering new and remanufactured products in different channels to the pricing decision.

In this paper we will introduce two scaling factors that characterize the separate sales channel, i.e. remanufacturing acceptance and customer's preference to buy remanufactured product in direct channel. We would further develop a pricing decision model for this situation, and study the effects of separating sales channel for new and remanufactured product to the supply chain’s profit.

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2. Literature review

Pricing strategy for dual channel in supply chain has been studied quite extensively. Most of the published works are dealing with pricing decision for single product that are sold in two different channels, namely traditional wall and brick stores, and internet or direct channel stores. Substitute products are also considered in some research. However, only a limited works explore pricing decision in a closed-loop supply chain with dual sales channel.

There are several works focusing on optimal pricing strategies for dual channel, and most of them use deterministic demand. Huang & Swaminathan assume a deterministic demand model where demand on a channel is affected by market potential, prices, and degree of substitution across channel [4]. They also consider the degree of autonomy for internet channel. The results provided are sub-optimal yet prevalent pricing strategies. In addition to pricing strategy, Dan et al. examine the effect of optimal decisions to retail services, both in centralized and decentralized dual-channel supply chain [5]. Stackelberg sequential game is applied to the decentralized approach where manufacturer is the leader and retailer is the follower. It is shown that retail services strongly affect manufacturer's and retailer's pricing strategies and profits. They also reveal that the degree of customer loyalty to the retail channel have significant effect on the retail services and pricing decisions. Zhang et al. study pricing decisions in a dual-channel system under different power structures, which are Manufacturer Stackelberg, Retailer Stackelberg, and Vertical Nash. The effect of product substitutability and relative channel status on pricing decisions are investigated under these power structures. It is shown that customer always get the most benefit from the vertical Nash game, while no power structure is always the best for the entire supply chain [6]. Chen et al. consider pricing policies in a supply chain with one manufacturer who sells a product via a retailer and internet channel, and the retailer also sells a substitute product made by another manufacturer. The pricing decisions are compared between Nash and Stackelberg game settings. They study the effect of model parameters to the profits, i.e. self-price sensitivity, cross-brand price sensitivity, and service level [7]. Hsiao & Chen study the case where not only manufacturer has the option to operate the Internet channel, but also retailer, or both. They classify customers into two segments, namely grocery shoppers and Internet shoppers, in which the title represents customer's channel preference. There are three strategies considered in the pricing decisions, which are grocery encroachment strategy, channel separation strategy with interior optimum, and channel separation strategy with corner optimum solution [8].

Pricing decision in dual-channel system also considers contracts. Cai et al. focus on simple price discount contracts in the pricing decision; while the dual-channel supply chain competition is discussed under game theory framework consists of Manufacturer Stackelberg, Retailer Stackelberg, and Nash game [9]. The results show that simple price contracts can improve supply chain performance under different game situations. There are two channel pricing strategies considered, i.e. consistent and inconsistent pricing. It is shown that consistent pricing may improve the Stackelberg leader. Furthermore, complementary agreement, such as profit sharing or two-part tariff; and this scheme brings a win-win solution for both parties.

The study on dual-channel system in a closed-loop supply chain with remanufacturing is scarce, even though several authors claim that market segmentation and channel separation can reduce cannibalization effect, in terms that lower priced remanufactured product might cannibalize the sales of the new product. Widodo et al. examine the financial benefit in applying two scenarios for sales return under dual sales channel structure [10]. They use two game theoretic approaches, which are Bertrand scheme and Stackelberg leader scheme. The first is a simultaneous pricing decision making, while the latter is a sequential decision with a leader and a follower. The results show that simultaneous process always performs better in terms of total channel profit. Ma et al. explore the effect of government-funded consumption-subsidy to the dual-channel closed-loop supply chain [11]. There are two types of customer, primary customer – who does not own an obsolete product and can purchase a new product directly; and replacement customer – who owns an obsolete product and should sell it before purchasing a new one. Manufacturer acts as a Stackelberg leader over the followers, i.e. the retailer and the e-tailer. The results indicated that the consumption-subsidy can increase the scale of closed-loop supply chain. Also, the manufacturer and the retailer get benefit from the subsidy, while the e-tailer's benefit is uncertain.

The closest work to ours is a study by Jiang et al. who investigate pricing strategy in a dual-channel supply chain system with remanufacturing using an agent-based modeling, due to the complexity of the system [12]. Also, in order to reduce the computational load in the process of finding optimal prices, a learning search algorithm is designed and implemented within the multi-agent supply chain model. They find that optimal profits can be improved by introducing direct channel and remanufactured product. The model parameters are also observed, consists of customer preference, direct channel cost, and remanufacturing cost, in order to find the effects on optimal prices and profits. Clearly, our work differs from Jiang's in three ways. First, Jiang's work only consider a manufacturer and a retailer, while our work includes a collector of used product. Second, we develop an analytical model that include several parameters to demonstrate the system behavior, and the optimum is found based on the characteristics of the model designed, not based on simulation. Third, we consider a short life-cycle product, where the demand is represented by a time dependent deterministic function to contain the short life cycle pattern. Therefore, our contribution is affirmed.

This study is an extension to the authors' pricing decision model under single channel approach [13], where new and remanufactured products are sold via the same sales channel. We would like to study the effect of separating the sales channel to the total profits of the supply chain.

3. Problem Definition

A closed-loop supply chain consists of three members, namely a manufacturer, a retailer, and a collector. The closed-loop is initiated by a manufacturer who makes new product that is sold at a wholesale price P_{nw} to the retailer. The new product is then released to the market by the retailer at a retail price P_n. After a certain period of time, some products reach their end-of-use and become the objects of used products collection. The used product would be acquired by the collector under a certain acquisition price, P_c. We assume that the collector only collects used products that meet the required quality level for the remanufacturing process. Therefore, all collected returns are transferred to the manufacturer at a price P_f, as the input for remanufacturing process. The remanufactured product is then sold via manufacturer's direct channel such as factory outlet or warehouse store, at a price P_r. The closed-loop separate channel system can be seen in Figure 1.

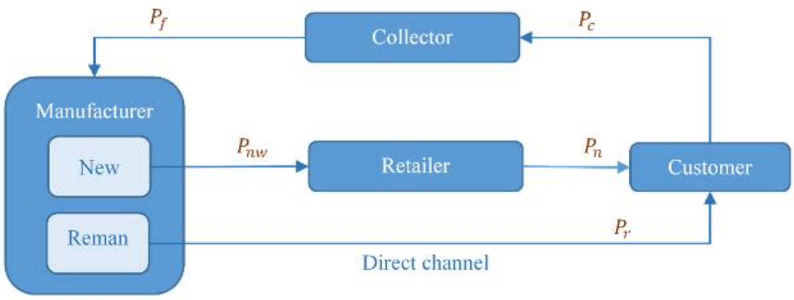

Figure 1. The closed-loop separate channel system

The product considered in this model is single item, short life-cycle, with obsolescence effect after a certain period, in term of obsolescence in function and desirability. Demand patterns are time-dependent functions which represent the short life-cycle pattern along the entire phases of product life-cycle, both for new and remanufactured products; and linear in price.

There are four time-frames considered in this model, as depicted in Figure 2. In the first interval [0, t_1], only new product is offered to the market. In second and third interval, i.e. [t_1, «] and [«, t_3], both new and remanufactured products are offered. The difference between second and third interval is on the segments of life-cycle phases for both types. During second interval, both new and remanufactured products are at the introduction-growth-maturity phases. In the third interval, the new product has entered the decline phase while remanufactured product has not. In the fourth interval [t_3, T], manufacturer has stopped producing new product and only offers remanufactured product which is assumed to be on the decline phase. The functions that represents these demand patterns are shown in [13]. The demand potentials for new and remanufactured product are the demand volumes accumulated over those four time-frames, excluding the effect of price sensitivity.

The total demands can be constructed by considering demand potentials, price sensitivity, and cross-channel sensitivity. Since cross-channel is also followed by a switch in customer's choice from buying new product to remanufactured one, a parameter that represents the scaling factor for remanufacturing acceptance is introduced in the model. These demand functions are similar to the ones in [8]. We apply two market segments based on Atasu et al. i.e. newness-conscious or high-end customers, and functionality-oriented or low-end customers [3].

Let υ be the customer's valuation to the new product,

- High-end customers would buy new product in retail stores when $\upsilon \geq P_n$
- High-end customers would buy remanufactured product in manufacturer's direct channel if $\beta_1 \upsilon \geq P_r$ and $\beta_1 \upsilon - P_r \geq \upsilon - P_n$
- Low-end customers would buy remanufactured product in manufacturer's direct channel if $\beta_2 \upsilon \geq P_r$ and $\beta_2 \upsilon - P_r \geq \upsilon - P_n$

We assume that low-end customers would not buy new product, because the price of new product is most likely higher than the price of remanufactured product ([2],[14][15][16]), and it is beyond their willingness to pay.

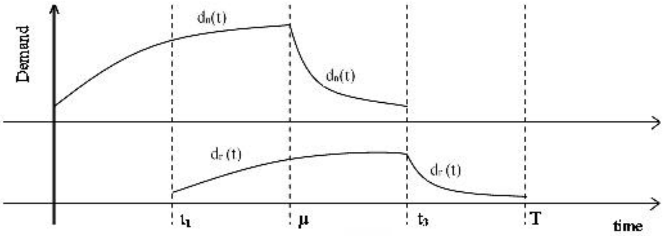

Figure 2. Demand pattern of a product with gradual obsolescence, over time

The scaling factor for remanufactured product, β_1, represents the devaluation of remanufactured product in high-end customer's view, as a result of quality perception. Remanufactured product is often perceived to be inferior to new product; therefore it has lower value in consumer's willingness to pay ([2],[17]). For example, let $\beta_1 = 0.7$, it means high-end customer values remanufactured product 70% of the product valuation, and he/she would only buy if the price offered (P_r) is lower than his/her valuation. Furthermore, when the utility of buying new product is higher ($\upsilon - P_n > \beta_1 \upsilon - P_r$), customer would not buy remanufactured product despite the positive utility ($\beta_1 \upsilon \geq P_r$).

The scaling factor for customer valuation to the remanufactured product sold via direct channel, β_2, represents the preference of low-end customers to purchase remanufactured product via direct channel. Customer tends to believe that factory outlet or warehouse stores operated directly by manufacturer would offer a lower price compared to the same product sold in a retail store, because of double marginalization. Therefore, customers who favor in functionality over newness would have higher preference when remanufactured product is sold via direct channel. Moreover, the green segment customer would prefer to purchase remanufactured product. They would find it easier and more convenient to locate the product when it is offered in a different sales channel. On the other hand, since new and remanufactured products are not offered hand-in-hand on the same location, the chance of cannibalization is reduced. Customer who has the intention to buy a new product would proceed to a retail store, with a lower risk to switch to buy remanufactured product.

After incorporating the scaling factors, the demand function is constructed for both segments. The product is assumed to be a high quality product such that low-end customer's willingness to pay is lower than the price of new product. Therefore, demand of new product is typically comes from high-end customer, while demand of remanufactured product would mostly come from low-end customer. There exists a channel interplay, where high-end customer might switch to buy remanufactured product, under a certain circumstances. On the other hand, we make an assumption that none of the low-end customer who decided to buy remanufactured product would switch to buy new product, since it is higher than their valuation or willingness to pay.

Demand of the new product can be expressed as

$$D_n = \begin{cases} \frac{d_{12}}{P_m}\left[P_n - \frac{P_n - P_r}{1-\beta_1}\right] & ; P_r \le \beta_1 P_n \quad \text{..............................(1a)} \\ \frac{d_{12}}{P_m}[P_m - P_n] & ; \beta_1 P_n \le P_r \le \beta_2 P_n \quad \text{..............................(1b)} \\ 0 & ; P_r \ge \beta_2 P_n \end{cases}$$

where d_{12} is the cumulative demand potential of new product during [0, t_3] (see Fig.2). The condition where "D_n is zero when $P_r \ge \beta_2 P_n$" represents the absence of channel interplay from D_r to D_n. The condition where "price of new product becomes too high that high-end customer will not buy new product" is implied in (1b), i.e. $P_n = P_m$; and $D_n = 0$ when $P_n = P_m$.

Demand function for remanufactured product is

$$D_r = \begin{cases} \frac{1}{P_m}\left[d_{34}\left(P_n - \frac{P_r}{\beta_2}\right) + d_{12}\left(\frac{P_n - P_r}{1-\beta_1} - \frac{P_r}{\beta_1}\right)\right] & ; P_r \le \beta_1 P_n \quad \text{..........(2a)} \\ \frac{d_{34}}{P_m}\left[P_m - \frac{P_r}{\beta_2}\right] & ; \beta_1 P_n \le P_r \le \beta_2 P_n \quad \text{..........(2b)} \\ 0 & ; P_r \ge \beta_2 P_n \end{cases}$$

where d_{34} is the cumulative demand potential of remanufactured product during [t_1, T] as in Figure 2. The condition where D_r is zero when $P_r \ge \beta_2 P_n$, represents a condition where the price of remanufactured product is too high, exceeding low-end customer's valuation or willingness to pay.

The optimal prices are found by applying the Stackelberg pricing game. It is started with the manufacturer as the leader, releasing the wholesale price and remanufactured product's price (reman price). This information is then used by the retailer, along with observation to the market demand, to decide the optimal retail price of the new product. Collector, on the other hand, observes the demand of remanufactured product and decides the optimal acquisition price. The collected used products are then transferred to the manufacturer, who further decides the wholesale prices for both new product sold to retailer and for reman price sold via direct channel.

4. Optimization Modeling

The optimization is carried out under sequential Stackelberg game with manufacturer as the leader. The objective of the pricing model is finding optimal prices that maximize profits. Since the demand functions are piecewise functions which are defined by different expressions at different interval, we need to consider the price decision for each interval. Four scenarios are introduced based on retailer's optimum retail price.

4.1. Retailer's Optimization

Retailer only sells new product, and the sales quantity follows D_n in equation (1). We have two intervals for reman price that determine the demand profile, which are $P_r \le \beta_1 P_n$ and $\beta_1 P_n \le P_r \le \beta_2 P_n$. Retailer's optimization will be conducted for these two intervals.

4.1.1. Retailer's optimization for $P_r \le \beta_1 P_n$

This interval implies that the price of remanufactured product sold via direct channel is lower than high-end customer's valuation. Hence, there would be a shift in high-end customer's preference. A customer who originally intends to buy new product, purchases remanufactured product in the end. The new product demand follows (1a), and the retailer's optimization problem is

$$\max_{P_n} \Pi_R = \frac{d_{12}}{P_m}\left[P_m - \frac{P_n - P_r}{1-\beta_1}\right](P_n - P_{nw}) \quad \text{……………………. (3)}$$

It is obvious that Π_R is concave in P_n, thus there exists optimal retail price that maximize the retailer's profit. Taking the first derivative condition yields

$$P_n^* = \frac{(1-\beta_1)P_m + P_r + P_{nw}}{2} \quad \text{…………………….. (4)}$$

Since $P_r \leq \beta_1 P_n$ then

$$P_r \leq \frac{\beta_1(1-\beta_1)P_m + \beta_1 P_{nw}}{2-\beta_1} \quad \text{…………………….. (5)}$$

Inequality (5) puts a restriction on reman price based on the manufacturer's initial released wholesale price and customer's maximum willingness to pay.

4.1.2. Retailer's optimization for $\beta_1 P_n \leq P_r \leq \beta_2 P_n$

Under this condition, the price of remanufactured product is higher than high-end customer's valuation, so they would not be interested in purchasing reman product. On the other hand, reman price is still lower than low-end customer's valuation. Demand of new product follows (1b) and the retailer's profit function is

$$\max_{P_n} \Pi_R = \frac{d_{12}}{P_m}[P_m - P_n](P_n - P_{nw}) \quad \text{…………………….. (6)}$$

Since Π_R is concave in P_n, thus there exists optimal retail price that maximize the retailer's profit and the first derivative condition is

$$P_n^* = \frac{P_n + P_{nw}}{2} \quad \text{…………………….. (7)}$$

This result is the same as the single channel approach in [13], where channel interplay does not exist. In this model, we consider two separate channel with a possibility of channel interplay, but in the second interval of reman price, the channel interplay diminishes. This approach is called channel separation strategy [8].

Furthermore, applying the restriction on reman price based on interval in D_n gives

$$\beta_1\left(\frac{P_m + P_{nw}}{2}\right) \leq P_r \leq \beta_2\left(\frac{P_m + P_{nw}}{2}\right) \quad \text{…………………….. (8)}$$

and therefore $\frac{\beta_1(1-\beta_1)P_m + \beta_1 P_{nw}}{2-\beta_1} \leq \beta_1\left(\frac{P_m + P_{nw}}{2}\right)$ …………………….. (9)

After determining optimal retail price based on two different intervals of reman price in demand function, we are able to find restriction for reman price based on the manufacturer's initial released wholesale price and customer's maximum willingness to pay. These restrictions further create four regions for reman price that leads to four scenarios, as seen on Figure 3.

- Scenario I: $P_r \leq \frac{\beta_1(1-\beta_1)P_m + \beta_1 P_{nw}}{2-\beta_1}$

Demand of the new product follows (1a) and demand of the reman product follows (2a). Optimal retail price is (4)

- Scenario II: $\frac{\beta_1(1-\beta_1)P_m + \beta_1 P_{nw}}{2-\beta_1} \leq P_r \leq \beta_1\left(\frac{P_m + P_{nw}}{2}\right)$

This scenario uses the boundary value of reman price, $P_r = \beta_1 P_n$. In order to encourage channel separation, we use demand functions (1b) for new product and (2b) for reman product. The optimal retail price is the corner point

$$P_n^* = \frac{P_r}{\beta_1} \quad \text{…………………….. (10)}$$

- Scenario III: $\beta_1\left(\frac{P_m + P_{nw}}{2}\right) \leq P_r \leq \beta_2\left(\frac{P_m + P_{nw}}{2}\right)$

This scenario finds optimum reman price within interior points of $\beta_1 P_n \leq P_r \leq \beta_2 P_n$. Demand of the new product follows (1b) and demand of the reman product follows (2b). Optimal retail price is (7)

- Scenario IV: $P_r \geq \beta_2 \left(\frac{P_m+P_{nw}}{2}\right)$

This scenario uses the other boundary value of reman price, $P_r = \beta_2 P_n$. Demand of the new product follows (1b) and demand of the reman product follows (2b). The optimal retail price is

$$P_n^* = \frac{P_r}{\beta_2} \qquad \text{……………………….. (11)}$$

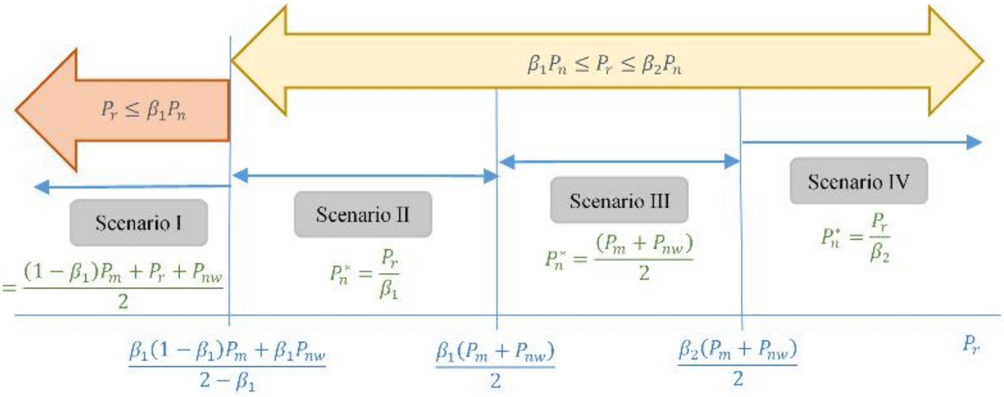

Figure 3. Reman price regions that leads to four scenarios

4.2. Collector's Optimization

In collector's optimization we apply an increasing return function that depends on the acquisition price, similar to [18]. The return function is represented by $\Theta(P_c) = \varphi P_c^{\theta} D_n$, where $\varphi > 0$ is a constant coefficient, and $\theta \in [0,1]$ is the exponent of the power function in return rate function, which determine the curve's steepness. This function indicates that collected returns is a portion of new product's sales, and the portion (or return rate) increases as acquisition price increases. Therefore, the collector should determine optimal acquisition price that would be high enough to acquire the needed quantity of returns, yet not too high as it would reduce the collector's profit. We use balanced quantity throughout the supply chain, so the collector only acquires as much as the demand of the remanufactured product. We have made an assumption that the collector would only collect used product that meet the quality criteria for remanufacturing process. Another assumption is made for the number of remanufacturing process applied to a product. We assume that used product collected should be originated from new product, which suggests single or one-time remanufacturing process for each product. A parameter is introduced here, c, unit collecting cost. The optimization is carried out for all scenarios.

4.2.1. Scenario I: $P_r \leq \frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1}$

The collector's optimization problem is

$$\max_{P_c} \ \Pi_C = \varphi P_c^{\theta} \frac{d_{12}}{P_n}\left[P_m - \frac{P_n-P_r}{1-\beta_1}\right]\left(P_f - P_c - c\right) \qquad \text{.......................... (12)}$$

The collector's profit function is concave and the optimum collecting price is

$$P_c^* = \frac{\theta(P_f-c)}{(\theta+1)} \qquad \text{.......................... (13)}$$

Applying balanced quantity yields

$$\frac{1}{P_n}\left[d_{34}\left(P_m - \frac{P_r}{\beta_2}\right) + d_{12}\left(\frac{P_n-P_r}{1-\beta_1} - \frac{P_r}{\beta_1}\right)\right] = \varphi P_c^{\theta}\frac{d_{12}}{P_n}\left[P_m - \frac{P_n-P_r}{1-\beta_1}\right] \qquad \text{.......................... (14)}$$

Substituting P_c with (13), we find

$$P_f^* = \left[\frac{d_{34}\left(P_m-\frac{P_r}{\beta_2}\right)+d_{12}\left(\frac{P_n^*\beta_1-P_r}{\beta_1(1-\beta_1)}\right)}{\varphi\, d_{12}\left(P_m-\frac{P_n^*-P_r}{1-\beta_1}\right)}\right]^{\frac{1}{\theta}} \cdot \frac{\theta+1}{\theta} + c \qquad \text{.......................... (15)}$$

with P_n as in (4)

4.2.2. Scenario II: $\frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1} \leq P_r \leq \beta_1\left(\frac{P_m+P_{nw}}{2}\right)$

The collector's optimization problem in this scenario is

$$\max_{P_c} \ \Pi_C = \varphi P_c^{\theta}\frac{d_{12}}{P_n}(P_m - P_n)(P_f - P_c - c) \qquad \text{.......................... (16)}$$

The collector's profit function is concave and the optimum collecting price is the same as (13). The optimal acquisition price in scenario II is the same as in scenario I, because the demand function does not have contribution is fulfilling the first derivative condition. Furthermore, applying balanced quantity gives

$$\frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right] = \varphi P_c^{\theta}\frac{d_{12}}{P_n}[P_m - P_n] \qquad \text{.......................... (17)}$$

Substituting P_c with (13) and P_n with (10), we find

$$P_f^* = \left[\frac{d_{34}\left(P_m-\frac{P_r}{\beta_2}\right)}{\varphi\, d_{12}\left(P_m-\frac{P_r}{\beta_1}\right)}\right]^{\frac{1}{\theta}} \cdot \frac{\theta+1}{\theta} + c \qquad \text{.......................... (18)}$$

4.2.3. Scenario III: $\beta_1\left(\frac{P_m+P_{nw}}{2}\right) \leq P_r \leq \beta_2\left(\frac{P_m+P_{nw}}{2}\right)$

The collector's optimization problem in this scenario is the same as scenario II, which is given in (16), so is the balanced quantity as in (17). Therefore the optimal acquisition price is (13). Substituting P_c with the optimum and P_n with (7), we get

$$P_f^* = \left[\frac{d_{34}\left(P_m-\frac{P_r}{\beta_2}\right)}{\varphi\, d_{12}\left(\frac{P_m-P_{nw}}{2}\right)}\right]^{\frac{1}{\theta}} \cdot \frac{\theta+1}{\theta} + c \qquad \text{.......................... (19)}$$

4.2.4. Scenario IV: $P_r \geq \beta_2\left(\frac{P_m+P_{nw}}{2}\right)$

In the fourth scenario, the collector's optimization problem is also the same as scenario II, which is given in (16), as well as the balanced quantity as in (17). Therefore the optimal acquisition price is (13), and by using P_n as in (11) we are able to express the transfer price as

$$P_f^* = \left[\frac{d_{34}}{\varphi\, d_{12}}\right]^{\frac{1}{\theta}} \cdot \frac{\theta+1}{\theta} + c \qquad \text{…………………….. (20)}$$

4.3. Manufacturer's Optimization

The optimal prices determined by the retailer and the collector become inputs in manufacturer's optimization in order to maximize his/her profit. The optimization problem is

$$\max_{P_{nw},\, P_r} \Pi_M = D_n(P_{nw} - c_{rw} - c_m) + D_r(P_r - P_f - c_r) \qquad \text{…………………….. (21)}$$

where c_{rw} is unit raw material cost for producing new product, c_m is unit manufacturing cost for producing new product, and c_r is unit remanufacturing cost for producing and selling remanufactured product in manufacturer's direct channel.

4.3.1. Scenario I: $P_r \leq \frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1}$

In manufacturer's optimization, reman price P_r is a decision variable, therefore it is necessary to impose its restriction on each scenario. The restrictions become the constraints to the optimization problem.

The optimization problem in scenario I is then stated as follows:

$$\max_{P_{nw},\, P_r} \Pi_M = \frac{d_{12}}{P_m}\left[P_m - \frac{P_n^*-P_r}{1-\beta_1}\right](P_{nw} - c_{rw} - c_m) + \frac{1}{P_n}\left[d_{34}\left(P_m - \frac{P_r}{\beta_2}\right) + d_{12}\left(\frac{P_n^*-P_r}{1-\beta_1} - \frac{P_r}{\beta_1}\right)\right](P_r - P_f^* - c_r) \qquad \text{…………………….. (22)}$$

subject to

(1) Reman price restriction for scenario I: $P_r \leq \frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1}$

(2) Supply constraint: $d_{12}\left[P_m - \frac{P_n^*-P_r}{1-\beta_1}\right] \geq \left[d_{34}\left(P_m - \frac{P_r}{\beta_2}\right) + d_{12}\left(\frac{P_n^*-P_r}{1-\beta_1} - \frac{P_r}{\beta_1}\right)\right]$

(3) Lower bound: $P_{nw} \geq P_{nw\_initial}$; $P_r \geq P_{r\_initial}$

$P_{nw\_initial}$ and $P_{r\_initial}$ are the initial wholesale and reman price released to the retailer and collector.

(4) Upper bound: $P_{nw} \leq (1-\beta_1)P_m + P_r$

where P_n^* and P_f^* are expressions given in (4) and (15), respectively.

This optimization problem is solved by computational approach because it becomes too complex for analytical approach and for finding closed-form solutions. We utilize Matlab for finding the solutions.

4.3.2. Scenario II: $\frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1} \leq P_r \leq \beta_1\left(\frac{P_m+P_{nw}}{2}\right)$

In this scenario, we use demand functions (1b) for new product and (2b) for reman product, in order to encourage channel separation. Since in scenario II $P_n^* = P_r/\beta_1$, the manufacturer's profit function becomes

$$\Pi_M = \frac{d_{12}}{P_m}\left[P_m - \frac{P_r}{\beta_1}\right](P_{nw} - c_{rw} - c_m) + \frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right](P_r - P_f^* - c_r)$$

It is obvious that the optimization process would seek the largest possible value for P_{nw} to maximize the profit function. Therefore, the optimum must occur on the boundary, i.e.

$$P_r = \frac{\beta_1(1-\beta_1)P_m+\beta_1 P_{nw}}{2-\beta_1}$$

The optimization problem in scenario II becomes

$$\max_{P_{nw}, P_r} \Pi_M = \frac{d_{12}}{P_m}\left[P_m - \frac{P_r}{\beta_1}\right] (P_{nw} - c_{rw} - c_m) + \frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right]\left(P_r - P_f^* - c_r\right) \quad \ldots\ldots\ldots\ldots\ldots (23)$$

subject to

(1) Reman price restriction in scenario II that provide the largest P_{nw}: $P_r = \frac{\beta_1(1-\beta_1)P_m + \beta_1 P_{nw}}{2-\beta_1}$

(2) Supply constraint: $d_{12}\left[P_m - \frac{P_r}{\beta_1}\right] \geq d_{34}\left[P_m - \frac{P_r}{\beta_2}\right]$

(3) Upper bound: $P_{nw} \leq P_m$
where P_f^* is the expression given in (18).
Similar to scenario I, this optimization problem is solved by computational approach due to its complexity

4.3.3. Scenario III: $\beta_1\left(\frac{P_m+P_{nw}}{2}\right) \leq P_r \leq \beta_2\left(\frac{P_m+P_{nw}}{2}\right)$

In scenario III, we use demand functions (1b) for new product and (2b) for reman product, and $P_n^* = \frac{P_n + P_{nw}}{2}$. The optimization problem become

$$\max_{P_{nw}, P_r} \Pi_M = \frac{d_{12}}{P_m}\left[\frac{P_m - P_{nw}}{2}\right] (P_{nw} - c_{rw} - c_m) + \frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right]\left(P_r - P_f^* - c_r\right) \quad \ldots\ldots\ldots\ldots\ldots (24)$$

subject to

(1) Reman price restriction for scenario III: $\beta_1 \frac{(P_n + P_{nw})}{2} \leq P_r \leq \beta_2 \frac{(P_n + P_{nw})}{2}$

(2) Supply constraint: $d_{12}\left[\frac{P_m - P_{nw}}{2}\right] \geq d_{34}\left[P_m - \frac{P_r}{\beta_2}\right]$

(3) Upper bound: $P_{nw} \leq P_m$
where P_f^* is the expression given in (19).

4.3.4. Scenario IV: $P_r \geq \beta_2\left(\frac{P_m+P_{nw}}{2}\right)$

In this scenario, reman price is high but is still within customer's willingness to pay. The model also take demand functions (1b) for new product and (2b) for reman product. Since in scenario IV, $P_n^* = P_r/\beta_2$, the manufacturer's profit function becomes

$$\Pi_M = \frac{d_{12}}{P_m}\left[P_m - \frac{P_r}{\beta_2}\right] (P_{nw} - c_{rw} - c_m) + \frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right]\left(P_r - P_f^* - c_r\right)$$

Since the profit function is linearly increasing in P_{nw}, the optimization process would seek the largest possible value for P_{nw} to obtain maximum profit. Therefore, the optimum must occur on the boundary, i.e. $P_r = \beta_2\left(\frac{P_m+P_{nw}}{2}\right)$.

Supply constraint can be omitted because $\frac{d_{12}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right] \geq \frac{d_{34}}{P_n}\left[P_m - \frac{P_r}{\beta_2}\right]$ implies $d_{12} \geq d_{34}$, which is obviously always true.

The optimization problem in scenario IV becomes

$$\max_{P_{nw}} \Pi_M = \left(\frac{P_m - P_{nw}}{2\,P_n}\right)\left[d_{12}(P_{nw} - c_{rw} - c_m) + d_{34}\left(\beta_2\left(\frac{P_m+P_{nw}}{2}\right) - P_f^* - c_r\right)\right] \quad \ldots\ldots\ldots\ldots\ldots (25)$$

subject to upper bound: $P_{nw} \leq P_m$
where P_f^* is the expression given in (20).

5. Numerical Example

Let the demand-potential's parameters for new product and remanufactured product be the same as the numerical example in the single channel approach in [13]. Selling horizon is one year and divided into four periods where t_1=1, μ=2, t_3=3, and T=4 in trimester units. The unit raw material cost for new product c_{rw}=1500, unit manufacturing cost c_m=1000, unit remanufacturing cost c_r=800, and unit collecting cost c=100. Maximum price is P_m=12000. Price and costs are given in thousands rupiah. Return rate parameters are φ =0.01, and θ=0.7. Remanufacturing acceptance (β_1) and scaling factor for customer valuation in remanufactured product sold via direct channel (β_2) for scenario I, II, III, IV are (0.8, 0.9), (0.7 and 0.8), (0.6 and 0.8), and (0.5 and 0.6), respectively. The results are given in Table 1. Manufacturer's profit is much higher than retailer in separate channel system, because she sells both new and remanufactured products, while retailer only sells new product.

Table 1. Numerical example for various scenarios	Scenario I	Scenario II	Scenario III	Scenario IV	Single channel [13]
β_1	0.80	0.70	0.60	0.50	
β_2	0.90	0.80	0.70	0.60	
p_n	7,700.00	8,571.43	9,500.00	10,000.00	9,889.78
p_r	6,346.70	5,647.74	5,673.33	5,597.54	8,318.83
p_{nw}	7,120.05	6,888.65	6,911.08	6,658.48	7,018.45
p_c	729.03	366.10	389.80	248.25	422.04
p_r	1,870.49	989.10	1,046.67	702.89	1,124.96
Π_M	4,948,745.78	4,090,846.09	3,291,706.88	2,714,894.15	2,391,233.07
Π_R^M	505,607.36	961,102.81	1,078,173.11	1,113,281.64	1,246,142.45
Π_C^R	205,065.44	186,107.37	150,977.65	56,087.71	145,869.03
Total profit	5,659,418.58	5,238,056.27	4,520,857.64	3,884,263.50	3,783,244.55
D_n	871.81	571.14	416.46	333.17	351.53
D_r	196.90	390.67	308.02	211.20	150.73

From the results in Table 1 we are able to show that applying separate channel can improve the total supply chain profit, compared to authors' previous model with single-channel approach [13]. In the single-channel model, the optimum remanufactured product's price is quite high because the product is offered through the same channel as new product, i.e. retail store. Therefore, double marginalization exists and it pulls the remanufactured product's price up and decreases the demand.

The scaling factor that represents remanufacturing acceptance, β_1, significantly influence pricing decisions and the profits of the supply chain members. It can be observed that lower remanufacturing acceptance leads to higher retail price. This is understandable because high-end customer is more reluctant to purchase reman product, and the retailer responds to it by increasing the retail price. However, higher retail price would decrease new product's demand. Even though retailer's profit is improving, manufacturer's profit is hurt by the small quantity of new product. Despite the potential profit gain that comes from reman product, manufacturer must consider the supply constraint that puts a limitation to reman quantity.

When reman acceptance is high, the optimization would likely fall into first scenario, which shows the best performance in terms of total supply chain's profit. In fact, manufacturer receives the most benefit from this scenario, but retailer does not. As remanufacturing acceptance gets higher, the chance of high-end customer switches from new to reman is also increasing. Retailer responds to it by lowering the retail price, to attract more high-end customer, and deter switching. However, as the Stackelberg leader, manufacturer optimize her profit after receiving retailer's pricing decision. Manufacturer finds optimal reman price that is higher than the initial reman price released to retailer. Therefore, the demand decreases for reman product but increases for new product. Since retailer has already priced the new product relatively low, her profit is relatively low, even though it is better than the initial condition when new product's demand is low. Collector can also benefits from this scenario, but not in consistent way. In this scenario, demand for reman product is high during retailer's optimization. Consequently, it is responded by high acquisition price, followed by high transfer price. Even though first scenario performs best, there is a limitation to it. If remanufacturing acceptance is very high, the reman product's demand can be too high that collector cannot acquired enough used product for remanufacturing process due to the supply constraint. This is a limitation to our model. Therefore, it is our intention to further explore a pricing strategy that includes green segment consideration, where reman price can be set higher than new product; and a condition where there is a switch from reman to new product.

Scenario II, III, and IV support channel separation strategy, where the effect of channel interplay is minimized. Scenario II is implemented when reman price lies at the borderline of switching from new to reman. When reman price is quite high relatively to high-end customer, then channel separation is naturally formed, and this is captured in scenario III. Scenario IV is applied on a situation where reman acceptance is low, customer preference to shop via direct channel is also low, while reman price is quite high but still at the borderline of no demand situation. The model would respond with pricing decision that placed new product and reman product according to the channel selection. There is a threshold for remanufacturing acceptance, as well as low-end customer preference to shop via direct channel, such that below those thresholds, selling reman product is no longer profitable.

The collector's optimum result is not following remanufacturing acceptance trend. As remanufacturing acceptance decreases, acquisition price and collector's profit changes inconclusively. Scenario I gives the best result to the collector. This can be explained by the high demand in reman product during retailer's optimization that is responded by collector's decision to collect high amount of returns. The attempt to collect sufficient used product is achieved by putting a high acquisition price that would be interesting enough for customer to sell their end-of-use product. Consequently, higher acquisition price is followed by higher transfer price, hence higher collector's profit.

Scenario III is the most similar case to model I. In the first model, even though new and reman products are sold through the same channel, but we did not consider cannibalization. The term cannibalization refers to a situation where a customer who initially plan to buy new product, but since reman product becomes more attractive then he/she ends up buying reman product. It usually is caused by reman product's lower price is very attractive to low-end or functionality-oriented customer. In this separate channel system, scenario III is only applied when reman price is within a certain interval between high-end customer's valuation towards reman product, and low-end customer's willingness to pay.

Scenario IV works best for the retailer because it is implemented on a situation where remanufacturing acceptance is low. Therefore, retailer can set a higher retail price. Despite lower demand caused by high retail price, retailer's profit is higher than the other scenarios.

The effect of scaling factor for customer preference in remanufactured product sold via direct channel (β_2) can also be investigated through the results in Table 1. Scenario IV would be effective on lower β_2. In this case, retail price is high and reman price is low compared to scenario I and III. Since the demand of new and reman product are also low, the total supply chain's profit is depleted. This is understandable because scenario IV is the strategy for a situation that is very close to no demand. However, collector suffers the most. When retailer can still benefit from high retail price despite low demand of new product, manufacturer still gain from selling both products, collector is hurt by small quantity of reman product's demand as well as low reman price, which means low transfer price. When we focus on the effect of β_2 within the same scenario, it can be observed that the lower β_2, the reman price, acquisition price, and transfer are getting lower, but retail price and wholesale price do not change, within the same scenario. However, when the scenario changes, lower β_2 leads to higher retail price.

6. Conclusion and Future Research

Pricing decision for a closed-loop supply chain with separate channel system has been presented. We develop the pricing model under four scenarios according to reman price: (a) it is lower than customer's valuation towards reman product, (b) it is at the borderline of customer's switch from new to reman (c) it lies between customer's valuation towards reman product, and low-end customer's willingness to pay, and (d) it is at the borderline of no demand situation. The optimization process is a sequential Stackelberg pricing game, with manufacturer as the leader. We found closed-form solutions for retailer's and collector's optimization, but for manufacturer's we use computational approach due to the complexity in the model. Two model parameters are studied, which are scaling factor for remanufacturing acceptance (β_1) and scaling factor for customer preference in remanufactured product sold via direct channel (β_2).

The results shows several points as follows

1. Pricing decision for new and reman products in a closed-loop supply chain with separate channel system can improve the total supply chain's profit compared to single-channel approach.
2. We propose four scenarios to tackle different reman price range, which improves the supply chain's profit profile. First scenario shows the best performance for manufacturer, but the opposite for retailer. Fourth scenario is the best one for retailer; while for collector, it is the worst.
3. Scenario II, III, and IV support channel separation strategy, where the effect of channel interplay is minimized

There are limitations to our study. First, we do not consider green segment. When reman price is quite high, the model leads to a no-demand situation. Second, in the absence of green segment, the switch from customer purchasing reman product to buying new product is not possible. Third, we assume balance quantity throughout the selling horizon, therefore the dynamic of product's quantity is not explored, as well as the inventory and salvage consequences. Fourth, this model use deterministic demand, while in reality, demand is random. These limitations can be explored in detail, and those would be avenues for further studies.

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