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# The Effect of Product Quality on the Pricing of New and Remanufactured Short Life-cycle Product

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**Abstract.** Remanufacturing is one of the recovery process that has become significant among many attempts to mitigate the landfill exhaustion, especially from mountain of wastes that come from short life-cycle products disposal. However, remanufactured product are often perceived to have lower quality compared to the new one. There are misconception about remanufactured product and lack of knowledge about its characteristics. On the other hand, several studies show that price and product quality have positive relationship. This paper investigates the effect of product's perceived quality on the pricing decision, to maximize the profit of the retailer and the manufacturer. We develop pricing decision model for new and remanufactured short life-cycle product in a closed-loop supply chain consists of a manufacturer and a retailer, where the manufacturer is a Stackleberg leader. We find that lower product's perceived quality would decrease the retail and wholesale prices of new and remanufactured products, but does not affect the new product's sales volume significantly. Also, the speed of change of demand influences the optimum total profit.

## 1. Introduction

Due to the rapid development in technology and research innovation, products' life-cycle has become shorter, especially for technology-based product such as electronics products. The period between launching a product and the introduction of newer model, newer design, or addition of new features has become shorter, and this has convinced customers to buy new product even though the previous one is still perfectly functioning. Usually, in the introduction phase, the product's demand would increase significantly, but when newer product or model is introduced, it would decrease rapidly. The demand characteristics of short life-cycle product is totally different from durable product. Therefore it is important to develop demand function that could capture the dynamics.

Recently, there are numerous attempt to study closed-loop supply chain, which is a study that is not only considering forward chain but also the reverse chain. In the reverse chain, a used product is collected and sent for a recovery process and then put back to the market with higher value than its discarded stage. This approach could extend product's useful life and slower the disposal rate. There are several recovery processes i.e. repair, refurbishing, and remanufacturing [1]; and remanufacturing is considered to be the ultimate form of recycling [2]. Remanufacturing is a process of transforming used product into "like-new" condition, where the value added during manufacturing is recaptured [3]. Several studies show that one of the critical factors to ensure successful remanufacturing is durability of the product. A short life-cycle product is also suitable for remanufacturing, and doing so could be beneficial for the environment and yet maintaining profitability [4].

Pricing decision is one of the important tasks in attempting to gain economic benefit from remanufacturing practices. Atasu et al. [5] point out that remanufacturing could become an effective marketing strategy, where manufacturer perform price discrimination to protect its market share. Also, a proper pricing strategy developed based on the market composition could avoid cannibalization effect i.e. remanufactured product cannibalizes the sales of new product [6]. Similarly, Souza [7, 8] shows that adding remanufactured product to the market alongside with the new product could expand the market, but on the other hand it could result in cannibalization, hence it is very critical to correctly decide the prices. Pricing decision model for remanufactured product has been widely studied. Regardless of remanufacturing product's key feature which is a product as good as the new one, remanufactured product is often perceived to have lower quality compared to the new product [9, 10]. Several pricing models accommodate this situation by differentiating the price of new and remanufactured products [6, 11, 12, 13, 14]. Gaur et al. [14] identify main drivers for purchase intentions through grounded theory-based interview, and indicate that price, brand, product quality, and service quality are the underlying factors behind customers' decision to purchase remanufactured products over new ones. van Weelden et al. [15] conducting in-depth interviews with consumers of remanufactured and new mobile phones, identify that misconception of remanufactured products, lack of awareness, lack of availability, and lack of the thrill of newness as the barriers for remanufactured mobile phones to be considered in the consideration phase. Wahjudi et al. [16] shows that product knowledge and purchase attitude have positive correlation with purchase intention. In this paper we would investigate the effect of product's perceived quality on the pricing of new and remanufactured short life-cycle products.

## 2. Optimization Modelling

We consider a closed-loop supply chain that consists of two members of the supply chain, i.e. retailer and manufacturer, under the selling horizon. Initially, manufacturer performs the production of new products, and customers can buy them via a retailer. After a particular period of time, customers start to sell end-of-use products to the manufacturer. The used product is then remanufactured and sent to the retailer. Now, customer have the option to purchase a new or remanufactured product. Therefore, during the selling horizon, both retailer and manufacturer sells new and remanufactured products with different time boundaries as in [12].

The pricing decision model is developed under a Stackelberg power structure, where manufacturer acts as the leader. We use the whole selling periods as the planning horizon. The model is developed based on backward induction. Retailer finds her optimum retail prices dependent on the wholesale prices. The manufacturer is then decide the wholesale prices to maximize her profit, after knowing retailer's move. In this model, we consider a single item short life-cycle product, which is typically prone to obsolescence in function and/or desirability. This type of product would have brief introduction, growth, and maturity phases, before declining. Product demand is constructed to cover the time frames according to the given time boundaries, and to allow price-dependent relation. Remanufactured short life-cycle product is often considered to be inferior to its new counterpart and customers' willingness to pay is typically lower for remanufactured short life-cycle product [17]. Therefore, a remanufactured product usually is more sensitive to price changes, or is having higher price sensitivity index.

The governing demand functions, for new and remanufactured product, are formulated as in [12]:

$$d_n(t) = \begin{cases} d_{n1}(t) = \frac{U}{1+ke^{-\lambda U t}};\ 0 \le t \le \mu \text{ where } k = \frac{U}{d_0 - 1} \\ d_{n2}(t) = \frac{U}{\lambda U(t-\mu)+\delta};\ \mu \le t \le t_3; \text{where } \delta = 1 + ke^{-\lambda U \mu} \end{cases} \tag{1}$$

$$d_r(t) = \begin{cases} d_{r1}(t) = \frac{V}{1+he^{-\eta V(t-t_1)}};\ t_1 \le t \le t_3\ ; \text{where } h = \frac{V}{d_{r0} - 1} \\ d_{r2}(t) = \frac{V}{\eta V(t-t_3)+\varepsilon}\ ;\ t_3 \le t \le T\ ; \text{where } \varepsilon = 1 + he^{-\eta V(t_3 - t_1)} \end{cases} \tag{2}$$

$d_n(t)$ is the demand pattern for new product and $d_r(t)$ is for remanufactured products. Total demand volumes during the selling horizon can be determined by integrating the demand functions with respect to time.

$$D_n = \int_0^{\mu} \frac{U}{1+ke^{-\lambda U t}} dt + \int_{\mu}^{t_3} \frac{U}{\lambda U(t-\mu)+\delta} dt = \frac{1}{\lambda} \ln\left(\frac{\delta}{(1+k)e^{-\lambda U \mu}}\right) + \frac{1}{\lambda} \ln\left(\frac{\lambda U(t_3-\mu)+\delta}{\delta}\right) \tag{3}$$

$$D_r = \int_{t_1}^{t_3} \frac{V}{1+he^{-\eta V(t-t_1)}} dt + \int_{t_3}^{T} \frac{V}{\eta V(t-t_3)+\varepsilon} dt = \frac{1}{\eta} \ln\left(\frac{\varepsilon}{(1+h)e^{-\eta V(t_3-t_1)}}\right) + \frac{1}{\eta} \ln\left(\frac{\eta V(T-t_3)+\varepsilon}{\varepsilon}\right) \quad (4)$$

We introduce a product quality factor ($g$), and "remanufactured product's quality coefficient" ($b$) to the pricing model to study its impact to the overall pricing decision. Product quality factor is considered inversely proportional to the customers' perceived quality. It means, the lower the product's perceived quality, the higher the factor value. We use product quality factor as a price coefficient in the demand function, with $P_m$ as the maximum price, therefore

Demand of new product = $D_n \left(1 - g \frac{P_n}{P_m}\right)$ (5)

Demand of remanufactured product = $D_r \left(1 - bg \frac{P_r}{P_n}\right)$ (6)

Under a symmetrical information setting, both retailer and manufacturer share the demand information. Retailer finds her optimum retail prices ($P_n$ for new product, and $P_r$ for remanufactured product) that maximize her profit. Based on retailer's optimum prices, manufacturer is then find the wholesale prices ($P_{nw}$, $P_{rw}$) that maximize manufacturer's profit. Considering that product has short life-cycle, we assume remanufacturing process is only applied to used product that is originated from new product, hence remanufacturing is only applied one time during the whole product's life.

Since this study is focusing on the effect of product's perceived quality to the pricing decision, we do not make an attempt to show detailed derivation of production and operational costs, and instead treat those costs as given parameters, which consist of unit manufacturing cost for new product ($c_n$), and unit manufacturing cost ($c_r$). Unit manufacturing cost includes raw material, manufacturing cost, etc. Unit remanufacturing cost includes cores' acquisition, collecting cost, remanufacturing cost, etc.

### *2.1. Retailer's Optimization*

Retailer's optimization model is constructed to find retail prices that maximize retailer's profit.

$$\max_{P_n, P_r} \Pi_R = D_n \left(1 - g \frac{P_n}{P_m}\right) \cdot (P_n - P_{nw}) + D_r \left(1 - bg \frac{P_r}{P_n}\right) \cdot (P_r - P_{rw}) \quad (7)$$

$\Pi_R$ is concave with respect to retail prices, therefore optimum prices can be found by solving the first derivative conditions, represented by

$$\frac{2D_n g}{P_m} P_n^{*3} - \left(\frac{D_n}{P_m}(P_m + gP_{nw}) + \frac{D_r}{4bg}\right) P_n^{*2} + \frac{D_r}{4} bg P_{rw}^{\ 2} = 0 \quad (8)$$

$$P_r^* = \frac{1}{2}\left(\frac{P_n^*}{bg} + P_{rw}\right) \quad (9)$$

### *2.2. Manufacturer's Optimization*

$$\max_{P_{nw}, P_{rw}} \Pi_M = D_n \left(1 - g \frac{P_n^*}{P_m}\right) \cdot (P_{nw} - c_n) + D_r \left(1 - bg \frac{P_r^*}{P_n^*}\right) \cdot (P_{rw} - c_r) \quad (10)$$

subject to (8), (9), and

$$0 \le P_{nw} \le P_n \le P_m\ ,\ 0 \le P_{rw} \le P_r \le P_n,$$
$$P_{rw} \le P_{nw}, P_{rw} \ge c_r, P_{nw} \ge c_n$$

Due to the optimization problem's complexity, we use a computational approach and use Matlab to find the optimum prices.

## 3. Results and Discussions

We use a numerical example to show the optimization results as well as the effect of product quality. The parameters are adopted from [12]. Demand capacity parameters for new product are $U = 1{,}000$, $D_0 = 90$, and demand capacity parameters for remanufactured product are $V = 500, D_{r0} = 50$. The speed of change in demands are $\lambda = 0.05, \eta = 0.05$. Selling horizon is divided into four time frames where $t_1$=1, $\mu$=2, $t_3$=3, and $T$=4. The unit manufacturing cost for new product $c_n$=2,500, unit remanufacturing cost $c_r$=1,800, maximum price is $P_m$=12,000. The product quality factor and remanufactured product's quality coefficient will be varied to study their effects on the pricing decision. The decision variables are $P_n$, $P_r$ and $P_{nw}$, $P_{rw}$ which represent the retail price of new product, retail price of remanufactured product, wholesale price of new product, and wholesale price of remanufactured product.

### *3.1. The effect of product's perceived quality*

In order to observe the effect of product's perceived quality to the price, product quality factor ($g$) and remanufactured product's quality coefficient ($b$) values are varied as follows: $g$=[1,1.1,1.2,1.3], $b$=[1,1.1,1.2]. The optimization results can be seen in Table 1.

**Table 1**. Numerical example's result – product's perceived quality

| b | g | Pn* | Pr* | Pnw* | Prw* | Profit M | Profit R | Total Profit | sales 1 | sales 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 10,010.05 | 8,283.40 | 7,160.40 | 6,556.75 | 2,405,395.59 | 1,263,036.99 | 3,668,432.58 | 336.71 | 175.79 |
| 1 | 1.1 | 9,112.54 | 6,938.78 | 6,638.91 | 5,593.44 | 2,011,823.96 | 1,049,809.35 | 3,061,633.31 | 334.39 | 165.50 |
| 1 | 1.2 | 8,369.89 | 5,917.85 | 6,201.97 | 4,860.80 | 1,698,048.66 | 880,820.62 | 2,578,869.28 | 330.99 | 154.45 |
| 1 | 1.3 | 7,745.09 | 5,124.07 | 5,830.49 | 4,290.38 | 1,443,561.69 | 744,586.82 | 2,188,148.51 | 326.80 | 142.61 |
| 1.1 | 1 | 9,966.70 | 7,553.90 | 7,174.29 | 6,047.16 | 2,327,957.35 | 1,216,073.10 | 3,544,030.44 | 344.05 | 169.47 |
| 1.1 | 1.1 | 9,076.21 | 6,336.90 | 6,650.05 | 5,172.81 | 1,949,223.29 | 1,011,791.62 | 2,961,014.92 | 341.15 | 158.16 |
| 1.1 | 1.2 | 8,338.80 | 5,412.45 | 6,211.00 | 4,507.63 | 1,646,954.87 | 849,788.35 | 2,496,743.22 | 337.30 | 145.97 |
| 1.1 | 1.3 | 7,718.00 | 4,693.40 | 5,837.84 | 3,989.59 | 1,401,688.11 | 719,176.58 | 2,120,864.69 | 332.76 | 132.89 |
| 1.2 | 1 | 9,930.44 | 6,949.53 | 7,185.58 | 5,623.69 | 2,265,131.33 | 1,177,681.12 | 3,442,812.45 | 350.18 | 163.28 |
| 1.2 | 1.1 | 9,045.73 | 5,838.00 | 6,659.06 | 4,823.18 | 1,898,708.75 | 980,903.15 | 2,879,611.90 | 346.82 | 150.92 |
| 1.2 | 1.2 | 8,312.63 | 4,993.34 | 6,218.24 | 4,214.03 | 1,606,056.41 | 824,792.39 | 2,430,848.80 | 342.62 | 137.58 |
| 1.2 | 1.3 | 7,695.10 | 4,336.13 | 5,843.66 | 3,739.52 | 1,368,556.27 | 698,954.22 | 2,067,510.49 | 337.80 | 123.26 |

The results show that the higher the product quality factor (which means the lower product's perceived quality in the market), the lower profit of both retailer and manufacturer. The effect is significantly recognized in the lower prices, both new and remanufactured, wholesale and retail prices. Interestingly, the new product's sales quantity is least affected. It is also observed that despite the shared prices decrease, the percentage of relative decrease is bigger for remanufactured products prices compared to new products'. The average relative decreases are 8.17%, 6.64%, 14.66%, 12.94% for new retail price, new wholesale price, remanufactured retail price, and remanufactured wholesale price. On the other hand, the relative decrease of profit is almost the same for manufacturer and retailer, i.e. 15.55% and 16.06% respectively.

The effect of remanufactured product's quality coefficient can be seen in Table 1 as well. The remanufactured prices are the ones most affected, with relative decreases 8.40% and 7.39% for retail and wholesale prices, on average. As for new product retail price, the relative decrease is relatively small, which is 0.40%. However, new product wholesale price is unexpectedly increasing even though the relative increase is very small i.e. 0.18%. Also, the sales of new product is increasing with average relative increase as much as 1.98%.

**Table 2**. Sensitivity analysis for demand's speed of change

| lmb | nu | g | Pn* | Pr* | Pnw* | Prw* | Profit M | Profit R | Total Profit | sales 1 | sales 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.01 | 0.01 | 1 | 9,947.48 | 7,544.21 | 7,178.86 | 6,045.26 | 2,267,507.28 | 1,182,401.60 | 3,449,908.87 | 341.92 | 157.29 |
| 0.01 | 0.01 | 1.1 | 9,061.04 | 6,330.04 | 6,653.34 | 5,171.62 | 1,901,415.72 | 985,390.07 | 2,886,805.79 | 338.64 | 146.79 |
| 0.01 | 0.01 | 1.2 | 8,326.74 | 5,407.52 | 6,213.35 | 4,506.90 | 1,608,782.46 | 828,910.09 | 2,437,692.55 | 334.48 | 135.48 |
| 0.01 | 0.01 | 1.3 | 7,708.40 | 4,689.83 | 5,839.50 | 3,989.16 | 1,370,988.95 | 702,562.22 | 2,073,551.17 | 329.68 | 123.34 |
| 0.05 | 0.05 | 1 | 9,966.70 | 7,553.90 | 7,174.29 | 6,047.16 | 2,327,957.35 | 1,216,073.10 | 3,544,030.44 | 344.05 | 169.47 |
| 0.05 | 0.05 | 1.1 | 9,076.21 | 6,336.90 | 6,650.05 | 5,172.81 | 1,949,223.29 | 1,011,791.62 | 2,961,014.92 | 341.15 | 158.16 |
| 0.05 | 0.05 | 1.2 | 8,338.80 | 5,412.45 | 6,211.00 | 4,507.63 | 1,646,954.87 | 849,788.35 | 2,496,743.22 | 337.30 | 145.97 |
| 0.05 | 0.05 | 1.3 | 7,718.00 | 4,693.40 | 5,837.84 | 3,989.59 | 1,401,688.11 | 719,176.58 | 2,120,864.69 | 332.76 | 132.89 |
| 0.1 | 0.1 | 1 | 9,967.19 | 7,554.14 | 7,174.18 | 6,047.21 | 2,318,950.58 | 1,211,421.47 | 3,530,372.04 | 342.54 | 169.02 |
| 0.1 | 0.1 | 1.1 | 9,076.59 | 6,337.08 | 6,649.97 | 5,172.84 | 1,941,609.01 | 1,007,880.25 | 2,949,489.26 | 339.67 | 157.73 |
| 0.1 | 0.1 | 1.2 | 8,339.11 | 5,412.58 | 6,210.94 | 4,507.64 | 1,640,463.78 | 846,469.56 | 2,486,933.34 | 335.84 | 145.58 |
| 0.1 | 0.1 | 1.3 | 7,718.24 | 4,693.49 | 5,837.80 | 3,989.60 | 1,396,117.35 | 716,340.54 | 2,112,457.89 | 331.33 | 132.54 |
| 0.2 | 0.2 | 1 | 9,966.87 | 7,553.98 | 7,174.25 | 6,047.17 | 2,309,829.83 | 1,206,621.89 | 3,516,451.72 | 341.31 | 168.22 |
| 0.2 | 0.2 | 1.1 | 9,076.34 | 6,336.96 | 6,650.02 | 5,172.82 | 1,934,019.82 | 1,003,914.03 | 2,937,933.85 | 338.44 | 156.99 |
| 0.2 | 0.2 | 1.2 | 8,338.91 | 5,412.49 | 6,210.98 | 4,507.63 | 1,634,089.16 | 843,160.54 | 2,477,249.70 | 334.62 | 144.89 |
| 0.2 | 0.2 | 1.3 | 7,550.52 | 4,508.70 | 5,736.54 | 3,856.41 | 1,326,646.52 | 679,581.67 | 2,006,228.19 | 328.66 | 127.85 |

### *3.2. Sensitivity analysis for demand's speed of change*
In order to study the effect of demand's speed of change, $\lambda$ and $\eta$, we varied $\lambda, \eta = [0.01,0.05,0.1,0.2]$. Table 2 shows the optimization results. The highest profit is attained at 0.05. This result shows that increasing speed of change in demand does not always increasing the profit. The lower the product's perceived quality, which means the higher product quality factor, the sales quantity is decreasing as well as the profits. While the first three values (0.05, 0.01, 0.1) show decreasing rate along with lower product's perceived quality, the last value, 0.2, shows an exception. The percentage of decrease is 8.93% when product quality factor is increasing from 1 to 1.2, then 8.12% from 1.1 to 1.2, and 9.45% from 1.2 to 1.3. It appears that for higher speed of change the effect of product quality becomes more significant.

## 4. Conclusion
This paper studies the effect of product quality on the pricing decision of new and remanufactured short life-cycle products in a closed-loop supply chain. We develop a pricing decision model involving product quality factor (which is inversely proportional to the product's perceived quality), and the optimization is conducted under Stackelberg pricing game with manufacturer as the leader. The results show that lower product's perceived quality could increase price sensitivity and hence decrease the sales quantity and the profits. The speed of change in demand influence pricing decision, when it reach a higher value, the effect of product quantity becomes more significant.

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