The effect of refurbished products' quality on recycling incentive strategies under retailer take-back mode

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Abstract
The paper studies the effect of quality of refurbished products on recycling incentive strategies under retailer take-back mode. With considering refurbished products' quality, we propose the revenue-sharing and cost-sharing strategies, and find the strategies do improve the return rate and the quality really influences the recycling incentive strategies.

Keywords: Quality of the refurbished products, Strategies, Return rate

INTRODUCTION

Colleting and refurbishing the used products can not only slow down the pressure of the resources and environment, but also can reduce the manufacturing cost for the manufacturers.

As so far, the researches about the recycling and remanufacturing focus on the selections of the recycling channels and the pricing of the remanufactured products. In the early stage, a research proposed three decentralized decision-making recycling modes, that manufacturers recycle the used products directly, the retailers' take-back mode and a third party is responsible for recycling (Savaskan et al. 2004). The research proved that the retailers who are most closely associated with consumers are responsible for recycling is the most effective way. However, differing from the Savaskan's study, a research which took the price of recycling, the wholesale and the retail prices as the decision variables has studied the recycling channels and found that the manufacturers recycling is the best mode at that condition (Qiaolung et al. 2008). Recently, under the assumption that new products and remanufactured products are same, the research about the conditions when the manufacturers should be responsible for recycling by themselves and when they should entrust a third party to recycle was obtained attention (Giovanni and Zaccour, 2014).

The researches mentioned above all took the assumption that new products and remanufactured products are same, however, the differences between the new and remanufactured products exist in actual production, and the differences often perform on the different qualities and the different recognition of customers to both products. Considering the different qualities between the new and remanufactured products, a model was developed to evaluate the optimal price and quantity of the products (Pokharel and Liang, 2012). Using the different recognition of customers to products to show the difference between the new and remanufactured products, a study has evaluated the effect of the remanufactured products' sale on the new products (Guide and Li, 2010). The pricing model was established for the new and remanufactured products, and the model has considered the preference of the customers to the new and remanufactured products (Abbey et al. 2015).

The researches which have considered the differences between the new and remanufactured products mainly concentered on pricing, but seldom focus on the recycling incentive strategies. Based on the different qualities of the new and remanufactured products, this paper proposes the revenue-sharing (RS) and cost-sharing (CS) recycling incentive strategies aim at improving the return rate under the retailer take-back mode. Furthermore, we study how the refurbished products' quality impacts on the return rate and profits of the manufacturer and retailer in different models.

MODEL ASSUMPTIONS AND NOTATIONS

Considering a CLSC consisting of a single manufacturer and a single retailer, the manufacturer can manufacture a new product directly from raw materials, or refurbish a product coming from recycling, and the retailer sales the products to consumers and has the responsibility to collect the used products. We consider there has existed the new products and refurbished products in the market, and the manufacturer has the capability of making the refurbished products, to some degree, like the new products, which can lead customers have the difficulties to distinguish the new products and the refurbished products. The manufacturer sets the whole sale price for per unit of product and the transfer price for per unit used product paid to the retailer. The retailer sets the selling price and collects used products for selling them to the manufacturer, the retailer also determines the return rate, which affecting the investment in the collection of used products.

Differing from the previous researches, we take the differences between the qualities of the new products and refurbished products into consideration. To encourage the retailer to collect the used products, we develop the RS and CS strategies which not only can do promote the retailer to improve return rate but also increase the profits of the CLSC supply chain. For each strategy, we characterize the optimal decision variables and the profits of the manufacturer, the retailer and the supply chain, respectively. To reveal the effect of refurbished products' quality on different recycling incentive strategies, we also examine the sensitivity of the optimal return rate, the manufacturer's profit and the retailer's profit in two different strategies to the refurbished products' quality.

The major notations used for modeling are as follows:

Decision variables:

w : Unit wholesale price of a product.

p : Unit retail price of a product.

τ : Return rate.

Parameters:

c_n : Unit cost of manufacturing a new product.

c_r : Unit cost of refurbishing a used product, where $c_r = \lambda q_r$, where λ is the refurbishing cost coefficient, that is to say, the unit cost of the refurbished product is linear with the quality of the refurbished product.

c : The average unit cost of a product, where $c = \tau c_r + (1-\tau)c_n = c_n - \tau\Delta$, where $\Delta = c_n - c_r$.

D: The demand of the products, where $D = \alpha - \beta p + \gamma Q$, where α is the market size, β is the elasticity of demand, and γ is the coefficient that represents the impact of quality on demand, and Q is the comprehensive quality level of the products on the market which decided by the qualities of the new products and the refurbished products.

q_n : Quality of the new products.

q_r : Quality of the refurbished products

A : Unit transfer price of a used product from the manufacturer to the retailer.

θ: Retailer's share for revenue or cost while making the RS strategy or the CS strategy ($0 \le \theta \le 1$).

I .The investment cost of collection, I is a function of τ , and is expressed as $I = h\tau^2$, where h is a scale parameter of used products return. It is a convex function of the return rate and the cost would rise nonlinearly with used products return rate up to certain level.

$\prod_i^j$: The profit function of participant i in model j. The superscript i will take values C, D, RS, CS, denoting the centralized model, decentralized model, RS model and CS model, respectively. The superscript j will take values M, R, S, denoting the manufacturer, the retailer and the supply chain, respectively.

Without loss of generality, we make the following modeling assumptions in this paper.

Assumption 1. The cost of manufacturing a new product is not less costly than refurbishing a used product, i.e. $c_r \le c_c$. Additionally, c_r and c_n is same for the refurbished products and new products, respectively.

Assumption 2. To ensure profitable refurbishing, the unit cost of collecting and handling a used product is not higher than the unit cost saving from remanufacturing, i.e., $A \le \Delta$.

Assumption 3. The market size α and the elasticity of demand β are positive, and $\alpha + \gamma Q > \beta c_n$.

Assumption 4. To guarantee the demand of the new products, here we consider that the quality of the refurbished products is not better than the new products', then we have $q_r \le q_n$

Assumption 5. In the supply chain, the manufacturer is the leader and the retailer is the follower.

In the CLCSs, by recycling and refurbishing the used products can decrease the cost for the manufacturer, therefore, the manufacturer hopes to take back as many used products as possible. Under the retailer take-back mode, the retailer determinates the return rate, thus, if the manufacturer hopes to get many used products he should set some strategies to promote the retailer to improve the return rate. In the following parts of this paper, we deepen our study of the optimal decisions and supply chain profits of the strategies.

RECYCLING INCENTIVE STRATEGIES

Considering a CLSC, which consists of a manufacturer and a retailer who gives a single product to end customers with constant demand dependent on price and the comprehensive quality level of the products on the market. To formulate the comprehensive quality level of the products on the market, here we adopt a Hotelling (Geylani et al., 2007; Hotelling, 1929; Sajeesh and Raju, 2010) model and assume that consumers are heterogeneous in the market and thus are uniformly distributed along a Hotelling-type straight line, with the new and refurbished products centers of the retailer located at both ends. Let x represent the distance of a consumer to the refurbished products center; thus, the distance to the new products center is 1- x. Moreover, f (x) ~ Uniform [0, 1]. And each consumer buys one unit product will incur a transportation cost t per unit of distance. Here we assume that the customer can obtain υq_n and υq_r utility when buying a new and refurbished product, respectively, where υ represents unit utility for each unit quality. As a result, the utility that a consumer buys a refurbished product is $U_r = 1 - tx + \upsilon q_r$, and the utility to buy a new product is $U_n = 1 - t(1-x) + \upsilon q_n$. Each customer decides to buy the product that should provide his or her highest utility, then the rate of new and refurbished products on the market are calculated as follows:

$$x_r = \int_{x \subset \Omega_r} f(x)x = \frac{t - \upsilon(q_r - q_n)}{2t} \tag{1}$$

$$x_n = \int_{x \subset \Omega_n} f(x)x = \frac{t + \upsilon(q_r - q_n)}{2t} \tag{2}$$

Where $\Omega_r = \{x : U_r \geq \max(U_n, 0)\}$, $\Omega_n = \{x : U_n \geq \max(U_r, 0)\}$. Then, we define the comprehensive quality level of the products on the market is

$$Q = \frac{t - \upsilon(q_r - q_n)}{2t} q_r + \frac{t + \upsilon(q_r - q_n)}{2t} q_n \tag{3}$$

In the rest of the current section, we formulate each model.

Completely Centralized Model (Model C)

In the centralized condition, the manufacturer and retailer are belonged to a section that they have the same goal that is to maximize the profit of the supply chain. In such situation, the retailer directly get the products with no pays to the manufacturer, and the manufacturer also obtain the used products with no pays to the retailer, thus, the model to calculate the profit is as follows:

$$Max \prod{}_{s}^{C} = (p - c_n + \tau\Delta)(\alpha - \beta p + \gamma Q) - h\tau^2 \tag{4}$$

By deriving Eq. (4) with respect to p and τ , we calculate the optimal decision variables and the profit of the supply chain, which are showed in Table 1.

Completely Decentralized Model (Model D)

As we all known that the manufacturer and retailer in the reality CLCS often make their decisions separately, their objective are to maximize their own profits. Therefore, the manufacturer's and retailer's profits in the decentralized condition can be stated as in Eq. (5) and Eq. (6), respectively.

$$Max\prod{}_{M}^{D}=(w-c_{n}+\tau\Delta-A\tau)(\alpha-\beta p+\gamma Q) \tag{5}$$

$$Max\prod{}_{R}^{D}=(p-w+A\tau)(\alpha-\beta p+\gamma Q)-h\tau^{2} \tag{6}$$

In the decentralized condition, the retailer makes his or her decisions depended on the information that the manufacturer sets the wholesale price. We use Stackelberg equilibrium in order to solve the problem in such a way that the manufacturer and retailer are considered as the leader and follower, respectively. And the optimal decision variables and the profits of the participants in the CLSC are also showed in Table 1. It is obvious that the optimal decision variables in decentralized condition are less than them in centralized condition. To improve the effectiveness of the supply chain in decentralized condition, we propose the below strategies.

Revenue-sharing Strategy (Model RS)

To improve the return rate and the effectiveness of the decentralized supply chain, the manufacturer chooses to share his profit coming from recycling and refurbishing with the retailer. We consider predetermined share θ of the sharing revenue for the retailer and 1-θ for the manufacturer, then we have the profits model as follows:

$$Max\prod{}_{R}^{RS}=[p-w+\theta\tau\Delta+(1-\theta)A\tau](\alpha-\beta p+\gamma Q)-h\tau^{2} \tag{7}$$

$$Max\prod{}_{M}^{RS}=[w-c_{n}+(1-\theta)(\Delta-A)\tau](\alpha-\beta p+\gamma Q) \tag{8}$$

By backward induction, we obtain all decision variables showed in Table 1. It is not too hard to find that under the RS strategy the manufacturer will give his all revenue coming from the recycling and refurbishing to the retailer under the RS strategy to maximize his profit.

Cost-sharing Strategy (Model CS)

Since the return rate has the relationship with the retailer's investment in collecting the used products, the improvement of the return rate means the increase of the retailer's investment. Thus, to improve the return rate and encourage the retailer to cooperate with the manufacturer, the CS strategy also can be an effective way for the manufacturer to alternate. We also consider the predetermined share θ of the collecting investment for the retailer and 1-θ for the manufacturer, then the retailer's and manufacturer's profits can be stated as follows:

$$Max\prod{}_{M}^{CS} = [w - c_n + (\Delta - A)\tau](\alpha - \beta p + \gamma Q) - (1-\theta)h\tau^2 \tag{9}$$

$$Max\prod{}_{R}^{CS} = (p - w + A\tau)(\alpha - \beta p + \gamma Q) - \theta h\tau^2 \tag{10}$$

By backward induction, the optimal decision variables also are showed in Table 1.From the optimal predetermined share in CS strategy, we know that the optimal predetermined share rate is related with the recycling price, the unit profit by collecting and refurbishing the used product.

Table 1-The optimal decisions under four different modes

	D	RS
w	$\frac{(\alpha+\gamma Q)(4h-2\beta A\Delta+\beta A^2)+\beta c_n(4h-\beta A^2)}{8h\beta-2A\beta^2\Delta}$	$\frac{(\alpha+\gamma Q)(4h-\beta\Delta^2)+\beta c_n(4h-\beta\Delta^2)}{8h\beta-2\beta^2\Delta^2}$
p	$\frac{(\alpha+\gamma Q)(3h-A\beta\Delta)+\beta c_n h}{4h\beta-A\beta^2\Delta}$	$\frac{(\alpha+\gamma Q)(3h-\beta\Delta^2)+\beta c_n h}{4h\beta-\beta^2\Delta^2}$
τ	$\frac{A(\alpha+\gamma Q-\beta c_n)}{8h-2A\beta\Delta}$	$\frac{\Delta(\alpha+\gamma Q-\beta c_n)}{8h-2\beta\Delta^2}$
D	$\frac{h(\alpha+\gamma Q-\beta c_n)}{4h-A\beta\Delta}$	$\frac{h(\alpha+\gamma Q-\beta c_n)}{4h-\beta\Delta^2}$
θ	/	1
$\prod_M$	$\frac{h(\alpha+\gamma Q-\beta c_n)^2}{2\beta(4h-\beta\Delta^2)}$	$\frac{h(\alpha+\gamma Q-\beta c_n)^2}{2\beta(4h-\beta\Delta^2)}$
$\prod_R$	$\frac{h(\alpha+\gamma Q-\beta c_n)^2(4h-\beta A^2)}{4\beta(4h-A\beta\Delta)^2}$	$\frac{h(\alpha+\gamma Q-\beta c_n)^2}{4\beta(4h-\beta\Delta^2)}$
$\prod_S$	$\frac{h(\alpha+\gamma Q-\beta c_n)^2(12h-\beta A^2-2A\beta\Delta)}{4\beta(4h-A\beta\Delta)^2}$	$\frac{3h(\alpha+\gamma Q-\beta c_n)^2}{4\beta(4h-\beta\Delta^2)}$
	C	CS

w	/	$\dfrac{(\alpha+\gamma Q)(16h-4\beta\Delta^2+\beta A^2)+\beta c_n(16h-2\beta A^2 4}{32h-\beta(2\Delta+A)^2}$
p	$\dfrac{2h(\alpha+\gamma Q+\beta c_n)-\beta\Delta^2(\alpha+\gamma Q)}{4h\beta-\beta^2\Delta^2}$	$\dfrac{(\alpha+\gamma Q)\varphi_1+\beta c_n(64Ah^2-16h\beta\Delta A^2-8h\beta A^3)}{[32h-\beta(2\Delta+A)^2](8h\beta A-\beta^2A^2(2\Delta+A))}$
τ	$\dfrac{\Delta(\alpha+\gamma Q-\beta c_n)}{4h-\beta\Delta^2}$	$\dfrac{(4\Delta+2A)(\alpha+\gamma Q-\beta c_n)}{32h-\beta(2\Delta+A)^2}$
D	$\dfrac{2h(\alpha+\gamma Q-\beta c_n)}{4h-\beta\Delta^2}$	$\dfrac{8h(\alpha+\gamma Q-\beta c_n)}{32h-\beta(2\Delta+A)^2}$
θ	/	$\dfrac{2A}{2\Delta+A}$
$\prod_M$	/	$\dfrac{4h(\alpha+\gamma Q-\beta c_n)^2}{\beta[32h-\beta(2\Delta+A)^2]}$
$\prod_R$	/	$\dfrac{4h(\alpha+\gamma Q-\beta c_n)^2(16h-2\beta A^2-4A\beta\Delta)}{\beta[32h-\beta(2\Delta+A)^2]^2}$
$\prod_S$	$\dfrac{h(\alpha+\gamma Q-\beta c_n)}{\beta(4h-\beta\Delta^2)}$	$\dfrac{4h(\alpha+\gamma Q-\beta c_n)^2(16h-\beta A^2+4\beta\Delta^2)}{\beta[32h-\beta(2\Delta+A)^2]^2}$

Where $\varphi_1=192Ah^2-\beta^2A^4(60+A)+16h\beta A(\Delta+2A)(2\Delta+A)-4h\beta^2\Delta^2(2\Delta+3A)$

ANALYSIS OF DIFFERENT STRATEGIES

The objective of the proposed strategies is to improve the return rate in the CLSC under the retailer take-back mode, and study how the quality of the refurbished products impact profits of the manufacturer and retailer. In this section, we focus on the mentioned purposes and give our findings and proofs as follows:

Proposition 1. The two strategies do encourage the retailer to improve the return rate in the decentralized condition. Relationships, $\tau^{CS}>\tau^{D},\tau^{RS}>\tau^{D}$ hold. And the return rate function is convex with the quality of the refurbished products in any modes.

Proof. Using τ^{D} divided by τ^{CS} and τ^{RS} minus τ^{D}, we have

$$\frac{\tau^{CS}}{\tau^{D}}=\frac{2\Delta+A}{2A}\frac{8h-2A\beta\Delta}{8h-A\beta\Delta-\beta\Delta^2-0.25\beta A^2} \tag{11}$$

$$\tau^{RS} - \tau^{D} = \frac{8h(\Delta - A)}{(8h - 2\beta\Delta^2)(8h - 2A\beta\Delta)} \tag{12}$$

Since $\Delta > A$, then

$$\frac{\tau^{CS}}{\tau^{D}} = \frac{2\Delta + A}{2A} \frac{8h - 2A\beta\Delta}{8h - A\beta\Delta - \beta\Delta^2 - 0.25\beta A^2} > 1 \tag{13}$$

$$\tau^{RS} - \tau^{D} = \frac{8h(\Delta - A)}{(8h - 2\beta\Delta^2)(8h - 2A\beta\Delta)} > 0 \tag{14}$$

To proof the relationship between the return rate and the quality of the refurbished products, here we take the optimal return rate in the RS strategy as an example. Deriving τ^{RS} with respect to q_r, we have

$$\frac{\partial \tau^{RS}}{\partial q_r} = \frac{\Delta\gamma(t + 2\upsilon q_r - 2\upsilon q_n)}{2t(8h - 2\beta\Delta^2)} \tag{15}$$

Then we can make the decision that when $q_r < q_n - \frac{t}{2\upsilon}$, it satisfies the condition $\frac{\partial \tau^{RS}}{\partial q_r} < 0$, when $q_r > q_n - \frac{t}{2\upsilon}$, it satisfies the condition $\frac{\partial \tau^{RS}}{\partial q_r} > 0$ .Proposition 1 is thus proved.

Proposition 2. Adopting the recycling incentive strategies is always good for both the manufacturer and the retailer to increase their profits. And the profit function for any participant is convex with the quality of the refurbished products in any modes.

Proof. Taking the profits of the manufacturer in the different modes as an example, using $\prod_M^D$ divided by $\prod_M^{RS}$ and $\prod_M^{CS}$, respectively. Then we have

$$\frac{\prod_M^{RS}}{\prod_M^{D}} = \frac{8h - 2\beta A\Delta}{8h - 2\beta\Delta^2} \tag{16}$$

$$\frac{\prod_M^{CS}}{\prod_M^{D}} = \frac{32h - 8\beta A\Delta}{32h - 4\beta\Delta^2 - 4\beta A\Delta - \beta A^2} \tag{17}$$

Since $\Delta > A$, then we have

$$\frac{\prod_M^{RS}}{\prod_M^{D}} = \frac{8h - 2\beta A\Delta}{8h - 2\beta\Delta^2} > 1 \tag{18}$$

$$\frac{\prod_M^{CS}}{\prod_M^{D}} = \frac{32h - 8\beta A\Delta}{32h - 4\beta\Delta^2 - 4\beta A\Delta - \beta A^2} > 1 \quad (19)$$

Thus, $\prod_M^{RS} > \prod_M^{D}$, $\prod_M^{CS} > \prod_M^{D}$ .Using the same method, we can proof that $\prod_R^{RS} > \prod_R^{D}$, $\prod_R^{CS} > \prod_R^{D}$. Deriving $\prod_M^{RS}$ with respect to q_r, we have

$$\frac{\partial \prod_M^{RS}}{\partial q_r} = \frac{h\gamma(\alpha + \gamma Q - \beta c_n)(t + 2\upsilon q_r - 2\upsilon q_n)}{t(8h\beta - 2\beta^2\Delta^2)} \quad (20)$$

Then we can make the decision that when $q_r < q_n - \frac{t}{2\upsilon}$, $\frac{\partial \prod_M^{RS}}{\partial q_r} < 0$, and $q_r > q_n - \frac{t}{2\upsilon}$, $\frac{\partial \prod_M^{RS}}{\partial q_r} > 0$ .Therefore, proposition 2 is proved.

For describing the above findings more clearly, here we use a simple numerical analysis that $c_n = 80$, $\lambda = 0.5$, $\alpha = 500$, $\beta = 5$, $q_n = 140$, $h = 80000$, $t = 2000$, $\upsilon = 10$, $\gamma = 0.7$. Figure 1 shows the effect of the refurbished products on the return rate in different strategies. From figure 1 we know that the two recycling incentive strategies can show their positive functions in improving the return rate, and the CS strategy is superior to the RS strategy in improving the return rate. Moreover, the return rate increases with the quality of the refurbished products increases when the quality reaches certain level.

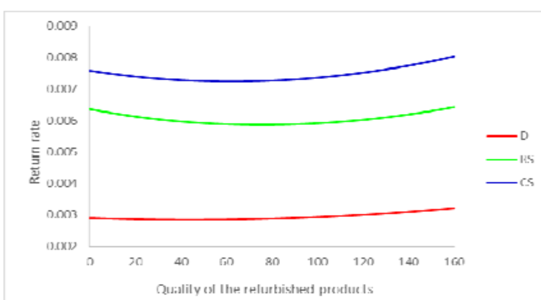

Figure 1-The effect of the refurbished products on the return rate in four strategies

Figure 2 and Figure 3 suggest that profit functions for any participant are convex with the quality of the refurbished products in different strategies. The two figures indicate that the proposed strategies do can help the manufacturer and the retailer to improve their profits in the decentralized condition, although, their function is not so obvious with the increase of the refurbished products' quality. From the profit figures, we know that the RS strategy is much better than the CS strategy for manufacturer when the quality of the refurbished products is less than certain level, but, this superiority becomes weaken gradually when the quality of the refurbished products exceeds the certain level. However, as for the retailer, the two strategies show a little difference in profits with the increase of refurbished products' quality.

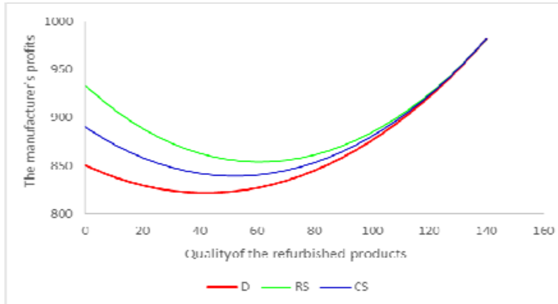

Figure 2-The effect of the refurbished products on the manufacturer's profits

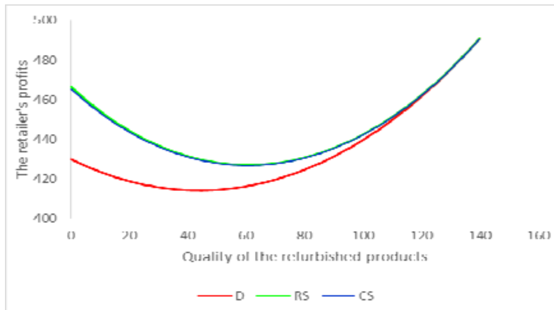

Figure 3-The effect of the refurbished products on the retailer's profits

Therefore, considering the return rates and the profits of the participants together, we suggest the RS strategy for the manufacturer when the quality of the refurbished products is less than certain level, and the CS strategy is a better decision when the quality of the refurbished products exceeds the certain level.

CONCLUSION

As for the theme of the recycling incentive strategies in the CLSCs, we propose the RS and CS recycling incentive strategies in this paper with considering the refurbished products' quality, which is always neglected in some other researches. By comparing the optimal return rate and the profits of the participants in the CLSC in different modes, we find that the proposed strategies can show their positive function in improving the return rate and the profits of the manufacturer and the retailer. Furthermore, the quality of the refurbished products, to some degree, impacts the return rate and the profits of the participants in different modes, which can show some scientific suggestions for the manufacturer to control the quality of the refurbished products and make the reasonable decisions with the dynamic changes of the refurbished products' quality.

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