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Strategic Remanufacturing Decision in a Supply Chain with an External Local Remanufacturer

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Abstract: This paper develops a model for remanufacturing decisions in a two-stage supply chain with one manufacturer, one retailer and one external local remanufacturer, who collects used products and then reproduces them into a new one if the manufacturer does not join in remanufacturing process. This paper is different from most of the extant studies about remanufacturing because they consider decisions of firms rather than supply chains. We mainly focus on the remanufacturing strategy of the manufacturer when there is a local remanufacturer. We derive the equilibrium results for all players and do some comparative studies under different cases. We find that product substitutability can invert the effect of manufacturer's extension decision on the retailer's profit. We also consider the effect of channel structure by comparing the decentralized channel with the centralized channel. We find that the manufacturer has a higher incentive to extend its product line in the centralized channel than the decentralized channel; and the competition can strengthen its motivation to extend the line.

Keywords: game theory, product line, remanufacturing, supply chain management

1. INTRODUCTION

Remanufacturing refers to economic process with recovering the end-of-life products, which were first produced by original equipment manufacturer (OEM). Remanufactured product often has the same function as the new one but cheaper, so it's a good alternative choice for some consumers. It is well known that, remanufacturing has a lower production cost and plays an important role in reducing environment burden. Adding remanufactured product is also a conveniently way to extend product line, which can help OEM attract more consumers and enlarge the market sale furthermore. However, an OEM may be not willing to participate in remanufacturing because remanufactured product may cannibalize sales of the higher-margin new products, as well as need a great amount of money to build a necessary reverse channel.

As a supply chain player, OEM's decision can be influenced by other participants, such as retailer and local remanufacturer. There exist some local remanufacturers, who have mature facilities for this process and will always take back the end-life products and reproduce them into new ones. These reproduced products can cannibalize the sales of the OEM's. For example, some Chinese machine tool manufacturers are puzzled with remanufacturing decisions because there is a big company Caterpillar extracts the big part of profit in this industry. Thus, it is very important for the OEM to make a trade-off between the remanufacturing or not when facing an outside competitor.

Channel structures can also have some effects on the OEM's decision. Having a retailer can be efficient, while they have advanced marketing strategy. However, a manufacturer just has its own sale channel just like Dell. We will also consider different channels' impact on the OEM's decision. In the centralized setting, we will first consider the supply chain without a local remanufacturer to see the cannibalization effect in different channel structures. Then we will look at the effect of the competition from a local remanufacturer if both sell

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products themselves. We first consider a situation without a local remanufacturer, so the system can be modeled as a Stackelberg game, where the OEM is the leader and the retailer is the follower. Then, we will consider the effect of the competition between the local remanufacturer and OEM on equilibrium outcome.

We have the major findings if there is a retailer in the distribution channel. Both retail and wholesale prices of the new product are lower if there is remanufactured product, and the competition will further decrease the prices for the new one. The OEM will have a higher incentive to extend product line if there is an outside competitor. From the comparison between the centralized and the decentralized channel, we know that if both OEM and local remanufacturer use their own channels, then the OEM will prefer to participate in remanufacturing to avoid the competition from other player. The competition is fierce in the centralized one.

2. LITERATURE REVIEW

Our work is closely related to two categories of research, one is remanufacturing decision while the other is product line design strategy.

There are many papers discuss remanufacturing related problems, for example, reverse channel design strategies [1], price and quantity decisions for the remanufactured product [2], remanufacturing decisions and so on. Savaskan et al. [1] consider the reverse channel selection problem and give out a coordination mechanism to induce the best collection effort for the retailer. Our paper is closely related to remanufacturing decision, which is often considered under the two-period condition [3-7]. Some of them did not consider the difference between the remanufactured and the new one. Majumder and Groenevelt [3] consider the impact of competition on the OEM's decisions both in the first and second periods. Others talk about the remanufactured product's cannibalization effect on the new product. Debo et al. [4] think about the production technology selection and pricing decisions from a manufacturer's view. Ferguson and Toktay [5] give out the condition under which the monopolist manufacturer will not join in remanufacturing. They also consider the manufacturer's entry-deterrent strategies when facing the external remanufacturing competition. Atasu et al. [7] think that there exists a green segment, while regard remanufacturing as a strategic marketing strategy. They show that price discrimination is a good strategy to defend the external competition. All the papers study the decisions without considering the retailers' reaction. Since there are always some interactions between manufacturers and retailers, we will focus on the remanufacturing strategy in a supply chain.

This paper is also related to papers talking about product line design strategies. Moorthy [8] considers a monopolist's product line design and pricing decisions, then Villas-Boas [9] extends the problem in a distribution channel and gives out the condition, under which the intermediary will carry all the products. Desai [10] then considers the effects of cannibalization in a product line problem. Product line problems are then considered together with other problems, such as different consumer choice modes [11-12], different introduction sequence [13-15] and advertisement related factors and so on. Liu and Cui [16] consider the product line decision in a supply chain with one retailer and one manufacturer. We consider the product line length decision of the OEM facing with an outsider competitor and concern the impact of competition on product line decision. This paper will consider the product extension decision of the OEM facing with the competition from local remanufacturer under different channel structures.

This paper contributes to the literature by considering the remanufacturing strategy in a supply chain with a external remanufacturer. We mainly focus on the interaction among the players instead of decisions in different periods. Additionally, we investigate the effects of the competition on the OEM's product line decisions.

3. THE BASIC MODEL

We consider a supply chain with one original equipment manufacturer (OEM), one local remanufacturer and one retailer, where all products are sold to consumers through the retailer. And all players are doing decisions based on their profits. As we only consider a single period, we assume the returns quantity and demand are independent of each other [17]. That is, we do not consider the constraints from the demands of the forward systems on the acquisition quantity of end-of life products. Since the market scale of the remanufactured product is smaller than the new one, this can be true in a mature market.

Firstly, we consider a supply chain without a remanufacturer to derive the optimal condition, under which the OEM will invest in remanufacturing. The OEM and the retailer play a Stackelberg game to decide the optimal prices. When there is a local remanufacturer, the OEM's remanufacturing strategy may be different because products from local remanufacturer can be regarded as a threat.

The time sequence of this game is as follows:

(i) The manufacturer decides whether to remanufacture the used product or not.

(ii) If the OEM participates in remanufacturing, he decides the wholesale prices for both new and remanufactured products; if he does not participate in remanufacturing, the local remanufacturer joins the market; and they decide the wholesale prices simultaneously.

(iii) The retailer decides the retail prices for both products.

We have the following notations:

a_i : the market size for product i , $i = n, r$, $a_n > a_r$;

d : the substitutability of the two products, $0 < d < 1$;

c_r : unit remanufacturing cost, including acquisition cost of used product;

c_n : unit manufacturing cost of the new product;

F : fixed cost when OEM joins in remanufacturing;

p : retail price for the new product when there is no remanufactured products;

w : wholesale price for the new product when there is no remanufactured products;

π_r : the profit function of retailer when there is no remanufactured product;

π_m : the profit function of OEM when there is no remanufactured product;

π_c : the profit function for the centralized channel when there is no remanufactured products;

π_j : the profit function of player j ($j = R, M$)when OEM reproduces;

π_C : the profit function for the centralized channel when OEM reproduces;

π_{m1} : the profit function of player m ($m = R, M, L$) when local remanufacturer reproduces;

π_{Cj} : the profit function for player n ($n = R, L$) in the centralized channel.

We assume that the remanufactured product is distinguishable from the new product, demand for the new product is $D_n(p_n, p_r) = a_n - p_n + dp_r$, while the demand for remanufactured product can be expressed as: $D_r(p_n, p_r) = a_r - p_r + dp_n$. Here, d means product substitutability, where $d = 0$ means two product are fully different, while $d = 1$ means they can be a fully substitutes for each other. When there is no remanufactured product in the market, we assume the demand for the remanufactured one as zero [3] by setting $p_r = a_r + dp_n$, so the demand for new one is: $D(p) = (a_n + da_r) - (1-d)p$.

When there is only one product in the market, the profit for the retailer is

$$\pi_r(p, w) = D(p - w) , \tag{1}$$

which is a concave function of p , i.e., $\partial^2 \pi_r(p, w) / \partial p^2 = -2 + 2d < 0$. By solving the first-order condition $\partial \pi_r(p, w) / \partial p = 0$ for p, we obtain the best reaction function $p(w) = \dfrac{a_n + da_r}{2(1-d)} + \dfrac{w}{2}$.

By considering the reaction function of the retailer, the profit function for the OEM $\pi_m(w, p) = (w - c_n)D$ can be expressed as

$$\pi_m(w)=\frac{1}{2}(w-c_n)[a_n+da_r-(1-d)w]\,, \tag{2}$$

which is a concave function of w. By solving the first-order condition, we can have the optimal wholesale price $w^*=\dfrac{a_n+(1-d)c_n+da_r}{2(1-d)}$. Inserting w^* into (2) and retailer's reaction, we can have the equilibrium profit for the OEM and the optimal retail price, furthermore we can have the retailer's profit

$$\pi_m^*=\frac{[a_n-c_n(1-d)+da_r]^2}{8(1-d)}\,, \tag{3}$$

$$\pi_r^*=\frac{[a_n-c_n(1-d)+da_r]^2}{16(1-d)}\,. \tag{4}$$

4. OEM'S REMANUFACTURING STRATEGY

4.1. OEM participates in remanufacturing

If the OEM participates in remanufacturing, the profit function of OEM can be expressed as

$$\pi_M(p_n,p_r,w_n,w_r)=D_n(w_n-c_n)+D_r(w_r-c_r)-F\,, \tag{5}$$

where the first (second) term mean profit from the new (remanufactured) product while the third term is the fixed cost for remanufacturing, including reverse channel investment built cost, process set up cost, administration cost, and so on.

In this way, the retailer's profit can be expressed as

$$\pi_R(p_n,p_r,w_n,w_r)=D_n(p_n-w_n)+D_r(p_r-w_r)\,, \tag{6}$$

By using backward induction technique, we can solve the subgame perfect Nash equilibrium (SPNE) of the Stackelberg game, and the extension range as well in Proposition 1.

Proposition 1. (i) When the fixed cost satisfy: $0<F<F_1=\dfrac{A_1+B_1(1-d^2)-(1+d)C_1}{8(1-d^2)}$, the OEM will join in remanufacturing, where $A_1=a_n^2+a_r^2+2a_na_rd$, $B_1=c_n^2+c_r^2-2a_rc_r-2a_nc_n-2c_nc_rd$, $C_1=[a_n-c_n(1-d)+da_r]^2$; (ii) When the OEM joins in remanufacturing, the optimal wholesale prices for the two products are $w_n^*=\dfrac{a_n+a_rd+c_n(1-d^2)}{2(1-d^2)}$, $w_r^*=\dfrac{a_r+a_nd+c_r(1-d^2)}{2(1-d^2)}$.

Proof. With two products, the retailer decides both the retail prices at the same time. Since the Hessian matrix of π_R over (p_n,p_r) is $\begin{pmatrix}-2 & 2d\\ 2d & -2\end{pmatrix}$, which is negative definite following from $0<d<1$. Solving the first-order conditions $\partial\pi_R/\partial p_n=0$ and $\partial\pi_R/\partial p_r=0$, we have the retailer's reaction function

$$p_n(w_n)=\frac{a_n+a_rd+(1-d^2)w_n}{2-2d^2}\ \text{and}\ p_r(w_r)=\frac{a_r+a_nd+(1-d^2)w_r}{2-2d^2}\,. \tag{7}$$

Inserting $p_n(w_n)$ and $p_r(w_r)$ into (5), we can obtain $\pi_M(w_n,w_r)$. We can show that $\pi_M(w_n,w_r)$ is a concave function of (w_n,w_r). Solving the first order conditions $\partial\pi_M^R(w_n,w_r)/\partial w_n=0$ and $\partial\pi_M(w_n,w_r)/\partial w_r=0$, we can have $w_n^*=\dfrac{a_n+a_rd+c_n(1-d^2)}{2(1-d^2)}$, $w_r^*=\dfrac{a_r+a_nd+c_r(1-d^2)}{2(1-d^2)}$. Further, we can obtain the SPNE retail prices: $p_n^*=\dfrac{a_n+a_rd}{2(1-d^2)}+\dfrac{w_n^*}{2}$, $p_r^*=\dfrac{a_r+a_nd}{2(1-d^2)}+\dfrac{w_r^*}{2}$, and equilibrium profits

$$\pi_M^*=\frac{a_n^2+a_r^2+2a_na_rd+(1-d^2)(c_n^2+c_r^2-2a_rc_r-2a_nc_n-2c_nc_rd)}{8(1-d^2)}-F\,; \tag{8}$$

$$\pi_R^* = \frac{a_n^2 + a_r^2 + 2a_n a_r d + (c_n^2 + c_r^2 - 2a_r c_r - 2a_n c_n - 2c_n c_r d)(1-d^2)}{16(1-d^2)}. \tag{9}$$

Comparing Equation (3) with (8), we know that if $\pi_M^* > \pi_m^*$, OEM will participate in remanufacturing, so we can have the extension range for OEM, that is, $0 < F < F_1$. ■

Proposition 1 shows that OEM will participate in remanufacturing only when the fixed cost is under certain amount. Since the expression of the remanufacturing boundary is complex, we will carry out sensitivity analysis on it later on. We can also see from the equilibrium wholesale price for the new product that it will increase with both market sizes of the two products. On one hand, OEM may increase the new product's wholesale price to gain a large marginal profit if the own market scale increases; on the other hand, when the market scale of the remanufactured one increases the demand for the new one can be increased as well for substitution effect. And the wholesale price for the remanufactured one has the same effect. By differentiating the equilibrium wholesale price with respect to d, we can have $\partial w_n^* / \partial d = \frac{a_n + a_r}{2(1-d)^2} > 0$, which means that OEM will increases wholesale price due to the enlarged market size.

By comparing the equilibrium decisions before and after extension, we have the following.

Corollary 1. When OEM participate in remanufacturing, the prices satisfy $w_n^* < w^*$ and $p_n^* < p^*$.

From Corollary 1, we can see that both the retail and wholesale prices are lower under remanufacturing. As there is a competitive product in the market, the retailer may want to decrease price to attract more consumers. The OEM may then cut prices of the products to compensate the retailer.

4.2. Local remanufacturer participates in remanufacturing

When OEM does not participate in remanufacturing, the local remanufacturer will do that. And we assume the local remanufacturer has its own reverse channel and production capacity. Both of them sell their products through a common retailer, in this way, the profit for the retailer can be expressed as (6).

So the profit function for the OEM is

$$\pi_{M1}(p_{n1}, p_{r1}, w_{n1}, w_{r1}) = D_{n1}(w_{n1} - c_n). \tag{10}$$

The profit of the local remanufacturer is

$$\pi_{L1}(p_{n1}, p_{r1}, w_{n1}, w_{r1}) = D_{r1}(w_{r1} - c_r). \tag{11}$$

Proposition 2 summarizes the range, under which OEM will join in remanufacturing if there exists a local remanufacturer and the wholesale prices.

Proposition 2. (i) If there is a local remanufacturer, OEM will join in remanufacturing when $0 < F < F_2 = \frac{A_1(4-d^2)^2 + [(4-d^2)^2 B_1 - 4C_2](1-d^2)}{8(1-d^2)(4-d^2)^2}$, where $C_2 = [2a_n + (a_r + c_r)d - c_n(2-d^2)]^2$; (ii) the wholesale price for the new one is $w_{n1}^* = \frac{2a_n + 2c_n + (a_r + c_r)d}{4-d^2}$, while the wholesale price for the remanufactured is $w_{r1}^* = \frac{2a_r + 2c_r + (a_n + c_n)d}{4-d^2}$.

Proof: By inserting the reaction functions (7) into (10) and (11), we obtain $\pi_{M1}(w_{n1}, w_{r1}) = \frac{1}{2}(w_{n1} - c_n)(a_n + dw_{r1} - w_{n1})$; $\pi_{L1}(w_{n1}, w_{r1}) = \frac{1}{2}(w_{r1} - c_r)(a_r + dw_{n1} - w_{r1})$. By solving the first-order conditions $\partial \pi_{M1}(w_{n1}, w_{r1}) / \partial w_{n1} = 0$ and $\partial \pi_{L1}(w_{n1}, w_{r1}) / \partial w_{r1} = 0$ for (w_n, w_r), we can obtain the optimal wholesale prices for both new and remanufactured product: w_{n1}^* and w_{r1}^*. Furthermore, we can obtain the equilibrium retail prices $p_{n1}^* = \dfrac{a_n + a_r d}{2(1-d^2)} + \dfrac{w_{n1}^*}{2}$ and $p_{r1}^* = \dfrac{a_r + a_n d}{2(1-d^2)} + \dfrac{w_{r1}^*}{2}$, while the equilibrium profits

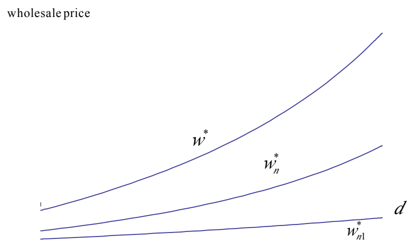
$$\pi_{M1}^* = \frac{[2a_n + (a_r + c_r)d - c_n(2-d^2)]^2}{2(4-d^2)^2}; \tag{12}$$

$$\pi_{L1}^* = \frac{[2a_r + (a_n + c_n)d - c_r(2-d^2)]^2}{2(4-d^2)^2}. \tag{13}$$

By comparing Equation (8) with (12), we know that if there is a local remanufacturer, OEM will extend its product line when $\pi_M^* > \pi_{M1}^*$, that is $0 < F < F_2$. ■

We can show the differences among the wholesale prices under different conditions through numerical examples, and default values of parameters are used as follows: $a_n = 40$, $a_r = 25$, $d = 0.35$, $c_n = 2$, and $c_r = 1.4$. Figure 1 illustrates the effect of substitutability on equilibrium wholesale prices.

Figure 1. New product's wholesale price versus substitutability



As can be seen in Figure 1, when the local remanufacturer joins in remanufacturing, the wholesale price for the new product is lower than the OEM does itself. That is, when there is the competition in the market, both players will decrease the price to attract more consumers. Though, we have already shown that the wholesale price is higher when there is just one product in the market, we can see from Figure 1 that the difference between the wholesale prices increases with product substitutability. That is, when product substitutability is high, the wholesale price difference is great.

To well understand the effect of competition, we define $\Delta F_1 = F_2 - F_1 = \dfrac{(4-d^2)^2(1+d)C_1 - 4(1-d^2)C_2}{8(1-d^2)(4-d^2)^2}$.

Figure 2 shows the effect of substitutability on ΔF_1.

We can see from Figure 2 that the extension range is widened by the competition. To avoid the cannibalization from the local remanufacturer, the OEM is willing to pay much to reduce the lost caused by the outsider competitor. We can also see that, ΔF_1 increases with market size, which is obvious for market scale increasing can help OEM to gain more profit. When product substitutability is higher, the difference of the range of extension becomes larger when there is a local manufacturer. As product substitutability increases, the competition increases, so OEM has a higher incentive to invest in remanufacturing to gain a higher profit.

Figure 3 illustrates the profit for the retailer under different conditions. Firstly, we consider the profit for the retailer if there is no local remanufacturer. When product substitutability is sufficiently low, having two products from OEM can make a higher profit than just holding just new one. Selling two differentiated products can help retailer attract more consumers and gain a higher profit. However, when product substitutability is high, just holding one product is more profitable. Higher substituted remanufactured product cannibalizes the demand of the new one, while the marginal profit is lower. So the profit for the retailer is lower under this condition. Additionally, the retailer's profit can be high if it sales products from not only OEM but also the local remanufacturer. As product line extension dampens the price competition, both OEM and local remanufacturer reduce their prices to compete for market, and in this way the retailer can make a larger marginal profit through product line pricing.

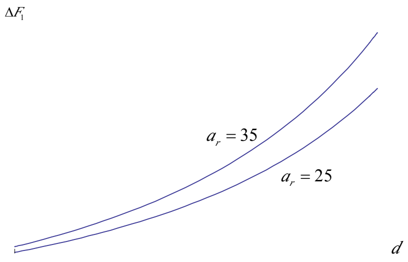


Figure 2. ΔF_1 **versus product substitutability**

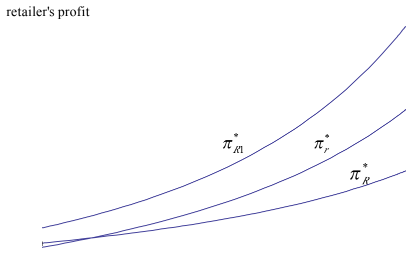


Figure 3. Retailer's profits versus product substitutability

5. REMANUFACTURING STRATEGY IN THE CENTRALIZED CHANNEL

5.1. Without remanufactured product

In the centralized case, we firstly consider the condition without remanufacturing. And the channel profit can be expressed as

$$\pi_c(p_c) = D_c(p_c - c_n) \tag{14}$$

We can show that $\pi_c(p_c)$ is a concave function of p_c. Thus, by solving the first-order condition, we can have the optimal retail price $p_c^* = \dfrac{a_n + a_r d + c_n(1-d)}{2(1-d)}$. Inserting p_c^* into (14), we obtain the equilibrium profit

$$\pi_c^* = \frac{[a_n - c_n(1-d) + a_r d]^2}{4(1-d)}. \tag{15}$$

5.2. OEM produces remanufactured product

If the manufacturer produces the remanufactured products, it has to decide the retail prices for both the new and the remanufactured products, simultaneously.

The profit function for the manufacturer can be expressed as

$$\pi_C(p_{cn}, p_{cr}) = D_{cn}(p_{cn} - c_n) + D_{cr}(p_{cr} - c_r) - F, \tag{16}$$

where the first part is the profit of the new product and the second part means the remanufactured products profit.

Proposition 3 shows the condition, under which OEM will take a part in remanufacturing in the centralized channel.

Proposition 3. When $0 < F < F_3 = \dfrac{A_1 + (1-d^2)B_1 - C_1^2(1+d)}{4(1-d^2)}$, the OEM will join in remanufacturing in the centralized condition.

Proof. From (16), we know the Hessian matrix over (p_{cn}, p_{cr}) is negative definite. Differentiating $\pi_c(p_{cn}, p_{cr})$ with respect to p_{cn} and p_{cr} respectively and solving the first-order condition, we can have the equilibrium retail prices for both new and remanufactured products: $p_{cn}^* = \dfrac{a_n + a_r d + c_n(1-d^2)}{2(1-d^2)}$, $p_{cr}^* = \dfrac{a_r + a_n d + c_r(1-d^2)}{2(1-d^2)}$. We can further obtain the equilibrium profit for the manufacturer.

$$\pi_C^* = \frac{a_n^2 + a_r^2 + 2a_n a_r d + (1-d^2)(c_n^2 + c_r^2 - 2a_n c_n - 2a_r c_r - 2c_n c_r d)}{4(1-d^2)} - F \tag{17}$$

By comparing equation (15) with (17), we can have the following extension range $0 < F < F_3$. ■

5.3. OEM does not produce remanufactured product

If the OEM and the local remanufacturer sell their products through their own channels, we can obtain their profit functions as following

$$\pi_{CM}(p_{cn1}, p_{cr1}) = D_{cn1}(p_{cn1} - c_n), \tag{18}$$

$$\pi_{CL}(p_{cn1}, p_{cr1}) = D_{cr1}(p_{cr1} - c_r). \tag{19}$$

Proposition 4. When $0 < F < F_4 = \dfrac{A_1(4-d^2)^2 + [(4-d^2)^2 B_1 - 4C_2](1-d^2)}{4(1-d^2)(4-d^2)^2}$, the OEM will join in remanufacturing in the centralized condition.

Proof. By solving the first-order conditions of (18) and (19), we can have the optimal retail prices $p^*_{cn1} = \dfrac{2a_n + 2c_n + (a_r + c_r)d}{4-d^2}$ and $p^*_{cr1} = \dfrac{2a_r + 2c_r + (a_n + c_n)d}{4-d^2}$, we can further have the equilibrium profits for the two players

$$\pi^*_{CM} = \frac{[2a_n + (a_r + c_r)d - c_n(2-d^2)]^2}{(4-d^2)^2}, \tag{20}$$

$$\pi^*_{CL} = \frac{[2a_r + (a_n + c_n)d - c_r(2-d^2)]^2}{(4-d^2)^2}. \tag{21}$$

By comparing (17) and (20), we can have the extension range. ■

In the central line, we still define the competition effect by: $\Delta F_2 = F_4 - F_3 = \dfrac{(4-d^2)^2(1+d)C_1^2 - 4(1-d^2)C_2}{4(1-d^2)(4-d^2)^2}$, which has the same structure as ΔF_1, but larger than the case in the decentralized condition, that is $\Delta F_1 < \Delta F_2$, which means the competition effect is larger in the centralized channel as OEM will be the only one to bear the loss of competition.

By considering Propositions 1, 2, 3, 4, we have Corollary 2, which shows differences of extension range in the different backgrounds.

Corollary 2. (i) If there is no local remanufacturer: $F_1 < F_3$; (ii) If there exists a local manufacturer: $F_2 < F_4$.

From Corollary 2, we know that in the centralized condition, the product extension range is larger than the decentralized condition. That is, OEM is more likely to extend its line in the central channel, which is because in the decentralized channel OEM always bears all the extending cost, so it has a lower incentive to extend the line.

6. CONCLUSIONS

If OEM reproduces a used product, the demand of the new products can be influenced by product substitutability. In this article we explore the condition, under which OEM will take a part in this process with an outside competitor. We first consider this problem in a decentralized channel with three players to see the effect of the competition from both inside and outside. Then we consider channel effect through a centralized case.

Our analysis gives some managerial insights for supply chain players. From the OEM's perspective, it will have a higher incentive to extend the product line by adding a remanufactured product if there is a local remanufacturer in the market. Furthermore, if it decides sell product itself instead of an intermediate retailer, he will be better off extending the product line. From the point of the retailer, holding two products from independent manufacturers can be profitable. However, when there is only an OEM in the market, selling just new one is benefit for the retailer when the product substitutability is large.

Here we just assume that retailer has no power but sells products from the OEM. Nonetheless, the retailer can be reluctant when holding two products with lower profit than just having a new one. In the future, we can consider the setting where the retailer is powerful enough to choose the products instead of hold the whole line.

Our work can be extended in the several other ways as well. Firstly, the quality difference of the new and the remanufactured can be endogenous to better show the competition effect. Secondly, if available quantity and price of the used product be considered would be valuable, while quantity and quality of used products can be a constraint for some OEM. Finally, consumer utility function can be used to better understand the consumer behavior.

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