Product Cannibalization Effect and Environmental Impact of Remanufacturing Outsourcing

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Abstract: More and more original product manufacturers (OPM) outsource to independent third party remanufacturers, due to the lack of remanufacturing infrastructure and technology, which also leads to the cannibalization effect of remanufactured products on new products. OPMs often adopt different channel strategies to deal with the problem of cannibalization. Therefore, this study constructs a supply chain model consisting of original product manufacturers and outsourced independent remanufacturers. OPM can adopt recycling strategy or remarketing strategy to deal with the cannibalization effect of remanufacturing outsourcing products, and explore the impact of recycling cost coefficient and other factors on supply chain equilibrium decision, economic benefits and environmental benefits. The results show that: (1) When the recycling cost coefficient is small, the recycling strategy can better cope with the problem of product erosion, that is, to increase the proportion of remanufactured products in the market. In addition, regardless of the recycling cost, the recycling strategy can increase the demand for new products compared with the remarketing strategy. (2) From the perspective of profit maximization, when the recycling cost coefficient $k < k_1$, the OPM's profit is higher under the recycling strategy, that is,$k_1 < k < k_2$, the OPM prefers to choose the recycling strategy when the recycling cost is small. At that time, remarketing can create a win-win outcome for both OPMs and outsourced independent remanufacturers, thus achieving Pareto improvement. (3) From the perspective of environmental impact, when the recycling cost coefficient is greater than a certain threshold, the recycling channel strategy is more environmentally friendly. (4) With the increase of remanufacturing cost, the profitability of original product manufacturers and outsourced independent remanufacturers will decrease, and the adverse impact on the environment will increase.

Keywords: Remanufacturing; Sales Strategy; Environmental Protection; Supply Chain

Introduction

Remanufacturing is an extension of the manufacturing industry chain and an important part of advanced manufacturing and green manufacturing. The US national standard defines remanufacturing as: “remanufacturing: a comprehensive and rigorous industrial process by which a previously sold,leased,used,worn,non-functional product or part is returned to an as-new or better-than-new condition,from both a quality and performance perspective,through a Controlled, reproducible and sustainable process ". Remanufacturing engineering includes the following two main parts: (1) The remanufacturing process. Mainly for the products that have reached physical and economic life and are scrapped, on the basis of failure analysis and life assessment, the products that contain use value and are no longer used due to functional damage or technical elimination are used as remanufacturing blank, and surface engineering and other technologies are used for processing, so that their performance and size can be quickly recovered, even exceeding the prototype products; (2) The performance upgrade of outdated products. Mainly for products that have reached the technical life or products that do not meet the requirements of sustainable development, we improve the technical performance of products, extend the service life of products and reduce environmental pollution through technical transformation and updating, especially through the use of new materials, new technologies and new processes.

According to statistics, remanufacturing can not only help enterprises save 40-65% of production costs, but also achieve energy saving of 60%, material saving of 70%, pollutant emissions of 80%, the average profit rate can reach 20%[1], and the economic benefits, social effects and ecological benefits are remarkable. However, due to the lack of remanufacturing equipment and capacity, most original product manufacturers often choose to outsource the remanufacturing business to authorized remanufacturers. Remanufacturers take this opportunity to continuously expand the profitable remanufactured product market. As a result, the remanufactured products cannibalization of new products, which seriously affects the profitability of original manufacturers.

1. Problem description and hypothesis

Facing the cannibalization effect caused by remanufacturing outsourcing, OPMs usually choose to adopt control strategies from different channels of the supply chain [2]. The first strategy is to control from the recycling end, that is, the OPMs are responsible for recycling waste products, and then outsource the remanufacturing business and the sales of remanufactured products to an independent third party remanufacturer, so as to cope with the cannibalization effect of remanufacturing by controlling the amount of recycling. The second strategy is to control from the sales side, that is, the OPM strictly controls the quantity of remanufactured products to deal with the cannibalization effect, and outsources the recycling and remanufacturing business of the waste products to the independent third party remanufacturer. These two strategies face the constraint of recycling waste products and the constraint of selling remanufactured products respectively. Therefore, from the perspective of economic benefits and environmental impacts, it is worth studying which strategy is more advantageous among the above two different channel strategies. To investigate the above issues, this paper constructs a supply chain model consisting of an original product manufacturer (OPM) and an independent third party remanufacturer (third-party remanufacturer) to explore the impact of different strategies of OPM and third-party remanufacturer on profit and environment.

Hypothesis 1: The total market size is constant and normalized to 1. Parameter γ represents the consumer's willingness to pay for the remanufactured good, where $\gamma \in [0,1]$. Consumers' willingness to pay for new products follows a uniform distribution of [0,1].

Hypothesis 1 represents a vertical differentiation model [3-5]. If new products and remanufactured products are priced at p_n and p_r respectively,The market demand is q_n and q_r respectively. The utility of consumers to purchase new and remanufactured products is $U_n(v) = v - p_n$ and $U_r(v) = v\gamma - p_r$. Therefore, consumers with willingness to pay of $[\frac{p_r}{\gamma}, \frac{p_n - p_r}{1-\gamma}]$ are more willing to purchase remanufactured products; While consumers with willingness to pay $[\frac{p_n - p_r}{1-\gamma}, 1]$ will buy the new product. The inverse demand functions for new and remanufactured goods are derived as follows:

$$p_n = 1 - q_n - \gamma q_r \qquad (1\text{-}1)$$

$$p_r = \gamma(1 - q_n - q_r) \qquad (1\text{-}2)$$

Hypothesis 2: The unit cost of remanufacturing c_r is lower than the unit cost of producing a new product c_n, i.e. $c_r < c_n$. Remanufacturing can effectively reduce manufacturing costs by 40-65% by reusing used parts [6,7]. According to Ferguson [8,9], it is assumed that the unit cost of remanufacturing is lower than the unit cost of producing the new product, i.e. $c_r < c_n$, thus indicating that the remanufactured product is a low-cost substitute for the new product.

Hypothesis 3: The recycling cost of used products is a quadratic function of the quantity of used products, that is $\frac{1}{2}kq_r^2k$, where k is the recycling cost parameter.

With the increase in the number of waste products to be recovered, the cost and difficulty of recovery are also increasing. Therefore, additional efforts are needed to recover more and more waste products, and the cost of recycling waste products increases non-linearly with the number of recycled products [10].

Hypothesis 4: The models all adopt a one-period model, that is, all decisions are considered in a one-period setting.

It is assumed that products previously available in the market can be returned to the original product manufacturer for reuse [11,12].

Hypothesis 5: The unit environmental impact of new products is greater than the unit environmental impact of remanufactured products, that is $i_n > i_u$, i_n and i_u denotes the total environmental impact of new products and remanufactured products respectively [13,14].

2. Model establishment and solution

This paper establishes two different channel strategy models. Model C indicates that the original product manufacturer directly participates in the remanufacturing business by recycling old components from consumers. The strategy of selling new products and remanufactured products through original manufacturers and independent remanufacturers respectively; Model R represents the strategy in which the original product manufacturer participates in the remanufacturing business by selling all the remanufactured goods to consumers, and both new products and remanufactured goods are sold through the original product manufacturer. π_x^i denote the profit of each participant in the supply chain. $\mathrm{x} \in (\mathrm{m}, \mathrm{a}, \mathrm{t})$ denotes the original product manufacturer, the outsourced independent remanufacturer and the entire supply chain, respectively; And $\mathrm{i} \in (\mathrm{C}, \mathrm{R})$ denote model C and Model R, respectively. The parameters and definitions of the model are summarized in Table 1.

Table 1 Parameters and definitions of the model

γ Consumer value discount for remanufactured goods
c_n Unit manufacturing cost of the new product
c_r Unit manufacturing cost of the remanufactured product
k Recovery cost factor
p_n^i The price of the new product in Model i,$\mathrm{i} \in (\mathrm{C}, \mathrm{R})$
p_r^i The price of remanufactured goods in Model i,$\mathrm{i} \in (\mathrm{C}, \mathrm{R})$
q_n^i The number of new products in model i,$\mathrm{i} \in (\mathrm{C}, \mathrm{R})$
q_r^i The number of remanufactured products in model i,$\mathrm{i} \in (\mathrm{C}, \mathrm{R})$
F license fees for remanufacturing in Model C
W Wholesale price of the new product in model R
π_x^i In model i, the profit of participant x,$\mathrm{x} \in (\mathrm{m}, \mathrm{a}, \mathrm{t})$, $\mathrm{i} \in (\mathrm{C}, \mathrm{R})$
e_n The environmental impact of the new product
e_r The environmental impact of remanufactured products
E^i Environmental impact in Model i,$\mathrm{x} \in (\mathrm{m}, \mathrm{a}, \mathrm{t})$, $\mathrm{i} \in (\mathrm{C}, \mathrm{R})$

2.1 Recycling channel strategy model

In Model C, new and remanufactured goods are distributed through the original manufacturer and the remanufacturer, respectively. The original manufacturer and the remanufacturer form a Stackelberg two-stage game. The decision sequence of the supply chain game model is as follows: first, the original manufacturer announces the licensing fee of the remanufactured product, then the original product manufacturing is which and the outsourced independent remanufacturer maximizes its profit by determining the optimal quantity of new products and remanufactured products. The profit functions of the original product manufacturer and the outsourced remanufacturer are:

$$\max_{q_n,f} \pi_m^C = (p_n - c_n)q_n + fq_r - \frac{1}{2}kq_r^2 \qquad (2\text{-}1)$$

$$\max_{q_r} \pi_a^C = (p_r - c_r)q_r - fq_r \qquad (2\text{-}2)$$

In Equation (2-1), the first item is the sales revenue of new products, the second item is the licensing fee of remanufactured products, and the third item is the input cost of recycling waste products; The first item in Equation (2-2) is the sales revenue of remanufactured products, and the second item is the licensing fee paid to the original product manufacturer. The equilibrium decision result of C can be obtained by the inverse induction method.

Theorem 1: The licensing fee, equilibrium quantity and profit in Model C are as follows:

$$f^* = \frac{2k\gamma - 4c_rk - 8c_r\gamma + 2c_nk\gamma + 8\gamma^2 + 4c_r\gamma^2 - 3\gamma^3 - c_n\gamma^3}{2(2k + 8\gamma - 3\gamma^2)}$$

$$q_n^{C*} = \frac{2k - 2c_nk + 8\gamma - 8c_n\gamma + 2c_n\gamma - 3\gamma^3 + c_n\gamma^2}{2(2k + 8\gamma - 3\gamma^2)}$$

$$q_r^{C*} = \frac{2(c_n\gamma - c_r)}{2k + 8\gamma - 3\gamma^2}$$

$$\pi_m^{C*} = \frac{(1 - c_n)^2}{4} + \frac{(c_n\gamma - c_r)^2(2k + 4\gamma - 3\gamma^2)}{(2k - 8\gamma + 3\gamma^2)^2}$$

$$\pi_a^{C*} = \frac{4\gamma(c_n\gamma - c_r)^2}{(2k + 8\gamma - 3\gamma^2)^2}$$

$$\pi_t^{C*} = \frac{(1 - c_n)^2}{4} + \frac{(c_n\gamma - c_r)^2}{2k - 8\gamma + 3\gamma^2}$$

Proof: By substituting equations (1-1) and (1-2) into Equations (2-1) and (2-2), the first-order conditions can be solved respectively

$$q_n^{C*} = \frac{2 - \gamma + f + c_n - 2c_n}{4 - \gamma}$$

$$q_r^{C*} = \frac{\gamma - 2f - 2c_r + \gamma c_r}{4\gamma - \gamma^2}$$

Then, by substituting, into Equation (2-1) and solving the first-order condition of

$$\max_{q_n,f} \pi_m^C = (p_n - c_n)q_n + fq_r - \frac{1}{2}kq_r^2,$$

we can obtain the licensing fee of remanufactured products

$$f^* = \frac{-4c_nk - 8c_r\gamma + 2k\gamma + 2c_nk\gamma + 8\gamma^2 + 4c_n\gamma^2 - 3\gamma^3 - c_n\gamma^3}{2(2k + 8\gamma - 3\gamma^2)}$$

By substituting f^* into $q_n^{C*}, q_r^{C*}, \pi_m^{C*}, \pi_a^{C*}$ and π_t^{C*}, the equilibrium result of Model C can be obtained, and the proof is completed.

2.2 Remarketing channel strategy model

In Model R, both new and remanufactured products are sold through the original product manufacturer. A two-stage Stackelberg game is played between the OPM and the outsourced independent third party remanufacturer. The decision sequence of the supply chain game model is as follows: first, the OPM decides the wholesale price of the remanufactured product, and then the OPM and the outsourcing third-party remanufacturer decide the optimal quantity of the new product and the remanufactured product. The profit functions of the original product manufacturer and the remanufacturer are:

$$\max_{q_n,w} \pi_m^R = (p_n - c_n)q_n + (p_r - w)q_r \qquad (2\text{-}3)$$

$$\max_{q_r} \pi_a^R = (w - c_r)q_r - \frac{1}{2}kq_r^2 \qquad (2\text{-}4)$$

In Equation (2-3), the first item is the sales revenue of new products, and the second item is the sales revenue of remanufactured products; The first item in Equation (2-4) is the income of the original product manufacturer from purchasing the remanufactured products, and the second item is the input cost of recycling the used products.

Theorem 2 Wholesale price, equilibrium quantity and profit in Model R are:

$$w^* = \frac{\gamma(2c_r + c_n k + 2c_n\gamma - 2c_r\gamma - 2c_n\gamma^2)}{k + 4\gamma - 4\gamma^2}$$

$$q_n^{R*} = \frac{k - c_n k + 4\gamma - 4c_n\gamma + 2c_n\gamma - 4\gamma^2 + 2c_n\gamma^2}{2(k + 4\gamma - 4\gamma^2)}$$

$$q_r^{R*} = \frac{c_n\gamma - c_r}{k + 4\gamma - 4\gamma^2}$$

$$\pi_m^{R*} = \frac{(1 - c_n)^2}{4} + \frac{(c_n\gamma - c_r)^2(2\gamma^2 - K - 2\gamma)}{2(k + 4\gamma - 4\gamma^2)^2}$$

$$\pi_a^{R*} = \frac{(c_n\gamma - c_r)^2}{2(k + 4\gamma - 4\gamma^2)^2}$$

$$\pi_t^{R*} = \frac{(1 - c_n)^2}{4} + \frac{\gamma(\gamma - 1)(c_n\gamma - c_r)^2}{(k + 4\gamma - 4\gamma^2)^2}$$

Proof: It can be obtained by substituting equations (1-1) and (1-2) into Equations (2-1) and (2-2) and solving the first-order conditions respectively

$$q_n^{R*} = \frac{1 - c_n - \gamma + w}{2(1 - \gamma)}$$

$$q_r^{R*} = \frac{\gamma c_n - w}{2\gamma(1 - \gamma)}$$

Then substituting q_n^{R*}, q_r^{R*} into the profit function of the remanufacturer, and solving the first-order condition of $\max_{w} \pi_m^R(w, q_n^*, q_r^*) = (p_n - c_n)q_n^* + (p_r - w)q_r^*$, we can obtain the wholesale price of the remanufactured goods $w^* = \frac{\gamma(2c_n + c_r k + 2c_n\gamma - 2c_n\gamma - 2c_n\gamma^2)}{k + 4\gamma - 4\gamma^2}$

The equilibrium result of model R can be obtained by substituting w^* into $q_n^{R*}, q_r^{R*}, \pi_m^{C*}, \pi_a^{C*}, \pi_t^{C*}$.

Theorem 3 guarantees $q_n > q_r > 0$that the production cost range of the remanufactured product is

$$c_n\gamma > c_r > \frac{c_n k - k - \gamma + 2c_n\gamma + \gamma^2}{1 + \gamma}$$

Proof: It can be solved $c_n\gamma > c_r > \frac{-2k + 2c_n k - 8\gamma + 8c_n\gamma + 3\gamma^2 - c_n\gamma^2}{2\gamma}$ by $q_n^{C*} > q_r^{C*} > 0$,

It is solved $c_n\gamma > c_r > \frac{c_n k - K - \gamma + 2c_n\gamma + \gamma^2}{1 + \gamma}$ by $q_n^{R*} > q_r^{R*} > 0$,

When $c_n\gamma > c_r > \frac{c_n k - k - \gamma + 2c_n\gamma + \gamma^2}{1 + \gamma}$,the conditions $q_n^{C*} > q_r^{C*} > 0$ and $q_n^{R*} > q_r^{R*} > 0$ can be satisfied at the same time , the certificate is completed.

Theorem 3 shows that the original product manufacturer is willing to enter the remanufacturing market when the remanufacturing cost is somewhat advantageous, i.e. $q_r > 0$. Moreover, the original manufacturer will produce a sufficient quantity of the new product when the cannibalization of the new product by the remanufactured product is not severe, i.e

$$c_r > \frac{c_n k - k - \gamma + 2c_n\gamma + \gamma^2}{1+\gamma}$$

2.3 Comparison of environmental impacts

Next, from the perspective of environment, the impact of different channel strategies on the sustainable development of the whole environment is discussed. E^C and E^R represent the environmental impacts of models C and R, where $E^C = i_n q_n^C + (i_n - i_u) q_r^C$, $E^R = i_n q_n^R + (i_n - i_u) q_r^R$.

Theorem 5 : When $k < \hat{k}(i_n, i_u)$, Model R is more environmentally friendly than Model C, i.e. $E^{C*} > E^{R*}$

Proof:$E^{C*} - E^{R*} = \frac{(c_r - c_n\gamma)(2ki_n - 4\gamma i_n - 7\gamma^2 i_n + \gamma^3 i_n - 2ki_r + 4\gamma i_r + \gamma^2 i_r)}{2(2k+8\gamma-3\gamma^2)(k+\gamma-\gamma^2)}$

By boundary conditions Δ^D, easy to know $c_r - c_n\gamma < 0$, $2k + 8\gamma - 3\gamma^2 > 0$ and $k + \gamma - \gamma^2 > 0$. for $2ki_n - 4\gamma i_n - 7\gamma^2 i_n + \gamma^3 i_n - 2ki_r + 4\gamma i_r + \gamma^2 i_r$, , exis $\hat{k}(i_n, i_u) = \frac{\gamma^3 i_n - 4\gamma i_n - 7\gamma^2 i_n + 4\gamma i_r + \gamma^2 i_r}{2i_r - 2i_n}$.

When $k < \hat{k}(i_n, i_u)$, then $2ki_n - 4\gamma i_n - 7\gamma^2 i_n + \gamma^3 i_n - 2ki_r + 4\gamma i_r + \gamma^2 i_r < 0$, i.e. $E^{C*} > E^{R*}$.

When $k > \hat{k}(i_n, i_u)$, then $2ki_n - 4\gamma i_n - 7\gamma^2 i_n + \gamma^3 i_n - 2ki_r + 4\gamma i_r + \gamma^2 i_r > 0$, i.e. $E^{C*} < E^{R*}$.

Theorem 5 shows that the environmental impact depends not only on the amount of remanufactured goods, but also on the amount of new goods. When the recycling cost coefficient is relatively low, i.e.$k < \hat{k}(i_n, i_u)$, the environmental impact of new products is higher in Model C than in Model R, i.e. $i_n q_n^{C*} > i_n q_n^{R*}$, this is due to the predominance of new products in model C in reducing environmental impact, and the increase in the number of new products leads to an increase in their environmental impact. And $(i_n - i_u) q_r^{C*} < (i_n - i_u) q_r^{R*}$ the increase in the number of new products leads to an increase in their environmental impact. In conclusion, in this case $E^{C*} > E^{R*}$, Model R is more environmentally friendly than Model C.

3. Conclusion

Firstly, when the recycling cost coefficient is small, the original product manufacturer will choose the recycling strategy to deal with the cannibalization effect, which is consistent with Guide and Li's research, indicating that the recycling strategy is more effective to deal with the cannibalization effect in the case of remanufacturing outsourcing. Secondly, when the recycling cost coefficient is lower than a certain threshold, the OPMs can adopt the recycling strategy to minimize the product cannibalization effect, but the OPMs' profit is not maximized at this time. However, when the recovery cost coefficient is moderate, the marketing strategy can create a win-win result for the OPM and the outsourcing independent remanufacturer. This conclusion is not consistent with the general view of corporate recycling responsibility. Under certain conditions, marketing strategy based on sales channel can also be the optimal strategy for OPMs. Therefore, when dealing with the product cannibalization effect of remanufacturing outsourcing, enterprise managers should pay special attention to the recycling cost of waste products, and choose a more appropriate channel strategy according to the recycling cost. Finally, due to the impact of the profitability of original product manufacturers, they often lack the awareness of improving the environment to recycle their own waste products. It is suggested that the government and environmental groups should not only formulate incentive measures to encourage remanufacturers to participate in the recycling of waste products, but also encourage original manufacturers to participate in the recycling of waste products.

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