Analysis for Patent Licensing Schemes and Remanufacturing Strategies with Platform

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Abstract: The manufacturer's patented products have core intellectual property rights, which poses legal issues for other remanufacturers to participate in remanufacturing. At the same time, the proportional commission in platform selling implies a new revenue allocation mechanism, which makes the patent licensing different from that in traditional supply chains. This study explores a Closed-Loop Supply Chain (CLSC) system where original equipment manufacturers (OEMs) hold product patents and decide on remanufacturing modes. According to the Stackelberg game theory and Optimization method, a game model with a leader (OEM) and a follower (platform) is then introduced, and the equilibrium characteristics with respect to production decisions and licensing decisions are derived. Basing analysis and simulation, the conclusions are got: Firstly, both in-house remanufacturing and royalty licensing are not the only dominant strategies, because recycling rate is related to the recycling scale parameter and the commission rate, and remanufacturing costs are key factors affecting both parties' profits. Secondly, fixed-fee licensing is an available mechanism for OEMs and platforms to reach cooperation on authorization.

Keywords: Royalty licensing; Fixed-fee licensing; Remanufacturing strategy; Platform commission; Stackelberg game;

1 Introduction

China proposes “Made in China 2025” to support the development of intelligent manufacturing, so optimizing the management process and improving the efficiency of the supply chain become important issues. As new products (especially electronic products) sold through the e-commerce platform gradually turn into waste products, remanufacturing is a good way to bring used products back to the market. So, in the face of the profit source brought by cost savings in remanufacturing, large platform operators also wish to join the remanufactured product market, such as Best-Buy Geek and Amazon Renewed. However, when a manufacturer's patented product is under the protection of patent law, any company that intends to remanufacture must obtain the OEM's patent license[1-2]. OEMs can utilize the core value resource - product patents - to ensure their critical position in the remanufacturing game. As the holder of product patents, manufacturers may choose to participate in remanufacturing by oneself or authorize it to the platform. There are two popular licensing schemes, which are royalty fee licensing and fixed-fee licensing. With the operation mechanism becoming mature, the platform provides manufacturers or third-party sellers with online marketplace and collect a sales commission. Commission

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rate is the key to distinguishing platform selling from traditional reselling, so the remanufacturing license in the context of platform selling may has different characteristics, which is worth studying.

In summary, there is a certain interaction between manufacturers' remanufacturing and patent licensing decisions and platform sales commissions. But as we've seen, the literature in CLSC does not consider the impacts of both patent authorization and platform selling on remanufacturing strategies. The relevant research is based on traditional supply chain (platforms are not included), and they mostly focus on the remanufacturing authorization between manufacturers [1], third-party remanufacturers [3-5], and retailers [6-7]. For example, Long et al. [8] indicates that in-house remanufacturing is superior to licensing retaliers, while Hong et al. [5] proposes an opposite finding. The above articles do not involve the impact of the platform commission on the authorized remanufacturing. Regarding the research on platform selling, researchers focus on the selection of sales mode and compare the differences between agency selling and reselling [9-10]. There is little research in the literature on platform selling that combines remanufacturing scenarios [11].

This study examines the effect of commission rate on the production decisions in different licensing scenarios of a supply chain, where the manufacturer cooperates with platforms for online selling. Further, we analytically discuss the impact of different licensing schemes on players' profits. The following questions will be addressed: (1) What is the equilibrium outcome in different remanufacturing models? (2) How does the sales commission influence the production, recycling rates, and the licensing fee? (3) Between two licensing patterns, which one can facilitate cooperation in patent authorization?

This article uses the Stackelberg game theory to analyze the decision-making problem between the OEM and platform, which is very common in supply chain research. The Stackelberg game is used to describe the leader-follower relationship between supply chain members. In each decision scenario, leaders make decisions based on the reactions of followers. This problem is generally solved by the backward induction method, that is, when the leader's decision is observed, the follower's decision is first solved.

2 Problem description and model assumptions

Considering a closed-loop supply chain composed of one OEM, one e-commerce platform, and consumers. The OEM produces new products, while it may also choose one of the three strategies: remanufacturing by itself, licensing relevant remanufacturing technology to the platform in royalty fee pattern, or in fixed fee pattern. OEMs determine the quantity (not price) of new products in this paper and equilibrium decisions can be obtained by using backwards induction.

The following assumptions need to be clarified for model construction.

(1) Assuming that the platform commission is exogenous[10-11].

(2) Assuming that the royalty licensing indicates that OEMs will charge fees for each unit of remanufactured products; While the fixed-fee licensing means that OEMs will charge a fixed fee to the platform, which is independent of the quantity of remanufactured products[0-0].

(3) Assuming that products already exist in the market, that is, OEM can remanufacture the product sold in the previous period[12]. We establish single-period models.

(4) To ensure a positive remanufacturing quantity, we assume $c_r < \delta c_n$.[10-11]

(5) In real life, only a portion of the sold products can be recycled and remanufactured. Assuming that the collection cost is $\frac{\eta}{2}(\tau q_n)^2$, where τ is the recycling rate and $\tau \in (0,1)$, and η is the scaling parameter[11-12].

(6) Assuming consumers' valuation of new products is v and v is uniformly distributed between 0 and 1, so the purchasing utility of a new product is $v - p_n$, and that of a remanufactured product is $\delta v - p_r$. δ refers to consumers' acceptance of remanufactured products, and $0 < \delta < 1$ indicates that consumers believe that the value perception of remanufactured product is always lower than that of the new product. This paper normalizes the scale of market to 1. Therefore, the demand for the two products is respectively $q_n = 1 - \frac{p_n - p_r}{1-\delta}$ and $q_r = \frac{p_n - p_r}{1-\delta} - \frac{p_r}{\delta}$.[12-13] In addition, the amount of recycling and remanufacturing is deterministic, i.e $q_r = \tau q_n$, so the inverse demand functions are $p_n = 1 - q_n - \delta\tau q_n$ and $p_r = \delta(1 - q_n - \tau q_n)$. Table 1 summarizes symbols appearing in this article.

Table 1. Parameters and variables used in models

Notation	Definition
q_n^i	Quantity of new products, $i \in \{I, LR, LF\}$
q_r^i	Quantity of remanufactured products, $i \in \{I, LR, LF\}$
p_n^i	Retail price of new products, $i \in \{I, LR, LF\}$
p_r^i	Retail price of remanufactured products, $i \in \{I, LR, LF\}$
τ^i	Recycling rate, $\tau \in (0,1)$, $i \in \{I, LR, LF\}$
f	Royalty fee
F	Fixed fee
c_n	Manufacturing cost, $0 < c_n < 1$
c_r	Remanufacturing cost, $0 < c_r < \delta c_n$
δ	Discount coefficient of consumer's valuation of remanufactured products, $\delta \in (0,1)$
η	Scaling parameter of the collection cost, $\eta > 0$
ϕ	Commission rate, $\phi \in [1\%, 25\%]$
Π_M^i	Profit of OEM, $i \in \{I, LR, LF\}$
Π_E^i	Profit of platform, $i \in \{I, LR, LF\}$

3 Model Formulation and Solution

3.1 In-house Remanufacturing Model (Model I)

In the model I, the OEM provides new and remanufactured products and make decisions on new product sales and recycling rate. The profit functions are as follows:

$$\max \pi_M^I = \big((1-\phi)p_n - c_n\big)\, q_n + \big((1-\phi)p_r - c_r\big)q_r - \frac{\eta}{2}(\tau q_n)^2 \tag{1}$$

$$\pi_E^I = \phi p_n q_n + \phi p_r (\tau q_n) \tag{2}$$

Proposition 1. When the condition for the existence of an equilibrium solution ($2\delta^2(1-\phi)^2 - \eta(1-c_n-\phi) - 2\delta(1-\phi)(1-c_n-\phi+c_r) < 0$) holds, the OEM's equilibrium strategy is given by

$q_n^I = \frac{2\delta^2(1-\phi)^2-\eta(1-c_n-\phi)-2\delta(1-\phi)(1-c_n-\phi+c_r)}{2(-1+\phi)(\eta+2\delta(1-\delta)(1-\phi))}$, and

$\tau^I = -\frac{2(\delta c_n-c_r)(1-\phi)}{2\delta^2(1-\phi)^2-\eta(1-c_n-\phi)-2\delta(1-\phi)(1-c_n-\phi+c_r)}$.

Substituting above optimal solutions into Eq. (1) and Eq. (2), we have $\Pi_M^{I*} = \frac{2c_r^2(1-\phi)-4c_nc_r\delta(1-\phi)+(\eta+2\delta(1-\phi))(-1+\phi+c_n)^2+2\delta^2(1-\phi)^2(-1+\phi+2c_n)}{4(\eta+2\delta(1-\delta)(1-\phi))(1-\phi)}$, $\Pi_E^{I*} = \frac{\phi\left(\begin{array}{c}\eta^2(-c_n^2+(1-\phi)^2)-4\delta c_r^2(1-\delta)(1-\phi)^2+8c_nc_r\delta^2(1-\delta)(1-\phi)^2+4\delta^3(c_n^2-2(1-\phi)^2)(1-\phi)^2+4\delta^4(1-\phi)^4\\ +4\delta\eta(1-\phi)(1-\phi+c_n)(1-\phi-c_n)+4\delta^2(-c_n^2+(1-\phi)^2)(-1+\phi)(-1+\eta+\phi)\end{array}\right)}{4(\eta+2\delta(1-\delta)(1-\phi))^2(1-\phi)^2}$

Corollary 1. $\frac{\partial \tau^I}{\partial \phi} > 0$, $\frac{\partial q_n^I}{\partial \phi} < 0$.

Corollary1 indicates that the recycling rate increases with the commission rate, while the number of new products show opposite characteristics. It is not difficult to understand that platform commission, as an expense for OEM engaged in e-commerce sales activities, will inevitably lead to an increase in the price of new products and a decrease in sales. Then, the recycling rate of used products will increase, indicating that in the presence of revenue sharing mechanism of the platform, OEMs prefer remanufacturing.

3.2 Authorized Remanufacturing with Royalty Licensing (Model LR)

In the model LR, we assume that CLSC members execute a Stackelberg game, and the OEM is the leader and the platform is the follower. The decision-making order is as follows: First, the OEM decides the volume of new products and sets the royalty fee; Second, the platform sets the recycling rate for used products. The objective functions of players are as follows:

$$\max \pi_M^{LR} = \left((1-\phi)p_n - c_n\right) q_n + f q_r \tag{3}$$

$$max\pi_E^{LR} = \phi p_n q_n + (p_r - c_r - f)(\tau q_n) - \frac{\eta}{2}(\tau q_n)^2 \tag{4}$$

Proposition 2. In Model LR, under the condition ($(2\delta+\eta)(1-\phi) > \delta^2$) that the equilibrium solution exists, the optimal quantity and recycling rate and royalty fee are given by $q_n^{LR} = \frac{1}{2}\left(1+\frac{c_n(2\delta+\eta)-c_r\delta}{\delta^2-(2\delta+\eta)(1-\phi)}\right)$, $\tau^{LR} = \frac{c_r-c_r\phi-c_n\delta}{\delta^2+(2\delta+\eta)(-1+\phi+c_n)-c_r\delta}$, and $f^{LR} = \frac{c_r(1-\phi)(\delta(2-\delta)+\eta)-\delta\left(\eta-\delta^2(1-\phi)-\eta\phi(2-c_n-\phi)+2\delta(1-\phi(2-c_n-\phi))\right)}{2(\delta^2-(2\delta+\eta)(1-\phi))}$.

Substituting above optimal solutions into Eq. (3) and Eq. (4), we have $\Pi_M^{LR*} = \frac{-2c_nc_r\delta+c_r^2(1-\phi)+(2\delta+\eta)(-1+\phi+c_n)^2+\delta^2(-1+\phi+2c_n)}{4((2\delta+\eta)(1-\phi)-\delta^2)}$ and $\Pi_E^{LR*} = \frac{\left(2\phi\left((2\delta+\eta)(1-\phi)-\delta^2\right)^2+2c_nc_r\delta(2\delta+\eta)(-1+3\phi)+c_r^2\left((2\delta+\eta)(1-\phi)^2-2\delta^2\phi\right)+c_n^2(2\delta+\eta)\left(\delta^2-2\phi(2\delta+\eta)\right)\right)}{8\left((2\delta+\eta)(1-\phi)-\delta^2\right)^2}$

Corollary 2. (1) $\frac{\partial \tau^{LR}}{\partial \phi} > 0$, $\frac{\partial q_n^{LR}}{\partial \phi} < 0$; (2) If $c_r < c_{r1}$, $\frac{\partial f^{LR}}{\partial \phi} > 0$; otherwise, $\frac{\partial f^{LR}}{\partial \phi} < 0$, where $c_{r1} = \frac{(\delta(2-\delta)+\eta)\left(\delta^2+(-1+c_n+2\phi)(2\delta+\eta)\right)-(2\delta+\eta)^2\phi^2}{\delta(\delta(2-\delta)+\eta)}$.

Corollary 2 indicates that the recycling rate increases with the platform commission, while the volume of new products decreases it. In addition, the royalty fee is crucial to the profitability of manufacturers and platforms, as shown in: when the remanufacturing cost is low, the royalty fee increases with platform commission, and vice versa, decreases with platform commission. As Corollary 1 states, the expenditure of sales commissions makes OEMs prefer remanufacturing. Therefore, if the cost advantage of remanufacturing is sufficiently significant, OEMs should increase royalty fees to avoid excessive cannibalization on their new product market.

3.3 Authorized Remanufacturing with Fixed-fee Licensing (Model LF)

In model LF, manufacturers license product technology to e-commerce platforms at a fixed fee, which means that the new and remanufactured products are in a pure competitive state. The decision-making order is: the OEM first determines the quantity of new products, and then the platform determines the recycling rate.

$$\max \pi_M^{LF} = \left((1-\phi)p_n - c_n\right) q_n + F \tag{5}$$

$$max\pi_E^{LF} = \phi p_n q_n + (p_r - c_r)(\tau q_n) - \frac{\eta}{2}(\tau q_n)^2 - F \tag{6}$$

Proposition 3. In Model LF, the optimal quantity and return rate are given by $q_n^{LF} = \frac{\eta(1-c_n-\phi)-\delta^2(1-\phi)+\delta(2(1-c_n-\phi)+c_r-\phi c_r)}{2(-1+\phi)(-\eta+\delta(-2+\delta+\delta\phi))}$ and

$\tau^{LF} = \frac{c_r(1-\phi)(-2\eta+\delta(-4+\delta+\delta\phi))+\delta\left((2\delta+\eta)(1+c_n+(-2+c_n)\phi+\phi^2)-\delta^2(1-\phi^2)\right)}{(2\delta+\eta)(\eta-\delta^2(1-\phi)-\eta(c_n+\phi)+\delta(2(1-c_n-\phi)+c_r-\phi c_r))}$.

Substituting above optimal solutions into Eq. (5) and Eq. (6), we have $\Pi_M^{LF*} = \Pi_M^{LF} + F = \frac{\left(2\delta c_n+(\delta(2+c_r)-\delta^2)(-1+\phi)+\eta(-1+c_n+\phi)\right)^2}{4(2\delta+\eta)(-1+\phi)(-\eta+\delta(-2+\delta+\delta\phi))} + F$. The expression of optimal platform's profit is complex, so we omit it here.

Corollary 3. (1) $\frac{\partial \tau^{LF}}{\partial \phi} > 0$; (2) If $\eta > \eta_1$, $\frac{\partial q_n^{LF}}{\partial \phi} < 0$; otherwise, $\frac{\partial q_n^{LF}}{\partial \phi} > 0$,

where $\eta_1 = \frac{\delta\left(-4c_n+\delta+\delta\phi(-2+2c_n+\phi)+\sqrt{\delta\left(4c_n\left(c_r-\delta(1-\phi)\right)(1-\phi)^2+\delta(1-\phi)^4+4c_n^2\delta\phi^2\right)}\right)}{2c_n}$.

Corollary 3 indicates that the volume of new products does not vary monotonically with platform commission. This conclusion is different from both Corollary 1 and Corollary 2. The reason is that in this situation, the fixed licensing fee is predetermined and exogenous. If the collection cost is too high, the competitiveness of remanufacturing will be weaken, and the demand for used products will be lower; an increase in commission fee will inevitably lead to a decrease in sales of new products. If the collection cost is low and the demand for remanufactured products increases, the number of new products will increase.

4 Comparative analysis

Proposition 4. By comparing model I and model LR, we conclude that: (1) OEM's profit: if $c_r < c_{r4}$, we have $\Pi_M^I > \Pi_M^{LR}$; otherwise, $\Pi_M^I < \Pi_M^{LR}$. (2) Platform's profit: $\Pi_E^I > \Pi_E^{LR}$. Here, $c_{r4} = \frac{c_n\delta\left(2\delta+\eta-2\phi(\delta+\delta^2+\eta)\right)}{2\delta+\eta-(4\delta^2+\eta)\phi+2\delta\phi^2(-1+\delta)}$.

Proposition 4, combined with Fig 1, shows the profits of players under various remanufacturing modes. Here, numerical examples are conducted, with each parameter assigned $\phi = 0.15$, $c_n = 0.5$, $\delta = 0.8$, $\eta = 2$, $c_r \in (0,0.40)$. It can be seen that for OEMs, when the remanufacturing cost is low ($c_r < 0.279$), in-house remanufacturing is favorable, while when the remanufacturing cost is high ($c_r > 0.279$), the royalty licensing is more favorable. But for platforms, remanufacturing organized by OEMs is always the optimal choice. This conclusion enriches existing studies, such as Long et al. [8] and Hong et al. [5]. Proposition 4 also suggests that under the royalty licensing scheme, OEM and platform cannot reach a cooperation on authorization.

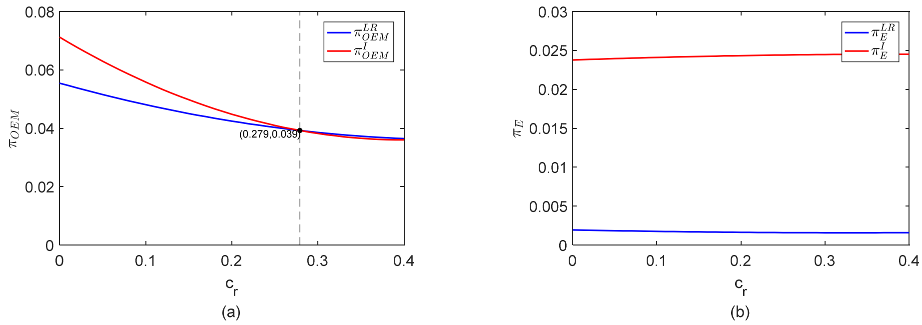

Fig. 1. Comparison of supply chain members' profits in model I and model LR

Proposition 5. By comparing model I and model LF, we can conclude that: (1) If $F > F_1 = \Pi_M^{I*} - \Pi_M^{LF}$, Fixed-fee licensing is superior for OEMs. (2) If $F < F_2 = \Pi_E^{LF} - \Pi_E^{I*}$, Fixed-fee licensing is superior for platforms. (3) If $F_1 < F < F_2$, OEM and platform cooperate on patent licensing.

Considering the uncertainty of fixed fee in the LF model, the preferences of OEMs and platforms vary depending on the remanufacturing role and fixed fee. Proposition 5 shows when the fixed fee meets certain condition ($F_1 < F < F_2$), both OEM's and platform's profits can be maximized simultaneously, achieving a win-win situation.

5 Conclusions

This article constructs three Stackelberg game models based on in-house remanufacturing and authorized remanufacturing with two licensing shemes, and the optimal decisions on licensing fee and recycling rate are solved. The important conclusions are summarized as follows.

We find that the commission rate has a significant effect. Firstly, an increase in commission rate makes it attractive to collect used products, and therefore leads to a higher recycling rate and more remanufacturing. Secondly, the royalty fee is not monotonic in the commission rate. Specifically, when the remanufacturing cost advantage is prominent, the royalty fee will increase with commission rate, which means that OEMs can transfer sales costs through licensing fees. Thirdly, in model I and model LR, the number of new products decreases with commission rate, but its monotonicity is related to the scaling parameter in fixed-fee licensing scenario. Comparative analysis of profits shows that the OEM and platform are unable to reach cooperation on authorization in fixed-fee licensing, as platform operators always prefer in-house remanufacturing mode. However, an appropriate fixed fee licensing strategy can make authorized remanufacturing more advantageous for both parties in model LF.

Future research can enrich our paper in these directions. Firstly, consumers' valuation of remanufactured goods from different firms maybe heterogeneous, but for simplification we suppose that consumers' valuation of remanufactured products is the same in in-house remanufacturing scenario and authorized remanufacturing scenario. Secondly, besides manufacturers, there are also some third-party remanufacturers engaging in e-commerce platforms sales. Therefore, operation strategies in complex competitive environments are also worth studying.

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