Decision Research on Patent Licensing of Original Manufacturers and Technology Innovation of Independent Remanufacturers

Xin Sheng
School of Management, Shanghai University, Shanghai 200444, China
1430824263@qq.com

Abstract. The innovation of remanufacturing technology is an effective way to keep the cost advantage of reproducts, and patent licensing facilitates the production of reproducts by independent remanufacturers. Considering people’s different preferences for reproducts and new products, we first construct an evolutionary game composed of original manufacturers and independent remanufacturers based on the theory and method of evolutionary game. Next, we study the evolutionary stable point and the influence factors of patent licensing and remanufacturing technology innovation strategy selection by Jacobian matrix. Finally, the model conclusion is verified by numerical analysis. The research shows that when the innovation level of remanufacturing technology is within a certain threshold, independent remanufacturers ultimately choose the technology innovation strategy, while original manufacturers always ultimately choose the patent licensing strategy and it is not affected by the innovation level of remanufacturing technology.

1. Introduction
Remanufacturing has attracted the attention of the social from all walks of life because of features of energy-saving, environmental protection and cost saving. More and more enterprises begin to enter the remanufacturing market, which aim to gain more benefits from the remanufacturing market. The government strongly encourages enterprises to carry out remanufacturing actively to promote the development of green manufacturing and energy-saving manufacturing [1, 2]. Xu [3] defines that remanufacturing is the sum of a series of technical measures or engineering activities to carry out mass repair, transformation and performance upgrading of the scrapped equipment and its parts with the remaining life, taking advanced technology and industrial production as means, based on the principles of high quality, high efficiency, energy saving, material saving and environmental protection. Due to the limitations of existing remanufacturing technologies, it is difficult for remanufactured products to have exactly the same quality, function and life span as new products, and consumers have different acceptance levels for both [4]. In recent years, China's remanufacturing in life assessment technology, composite surface engineering technology, nano surface engineering technology, which made major breakthroughs, and formed the remanufacturing technology with Chinese characteristics [5]. At the same time, the current development of remanufacturing in China still faces various challenges and development bottleneck [6].
The importance of technology driving and innovation to the further development of remanufacturing is self-evident, and our country is also strongly supporting the innovation activities of remanufacturing. The innovation in remanufacturing involves two aspects: First, it is about reducing the cost of remanufacturing by technological innovation of new products (such as disassembly technology and so on); The second is to carry out technological innovation directly in the remanufacturing to reduce cost and improve performance. Huang et al. [7] studied the influence of technological innovation on both sides when manufacturers adopted technological innovation strategy to deal with the competition of remanufacturers. Ji and Liu [2] analyzed the formation process of internal and external rules of product eco-innovation oriented to remanufacturing by the method of evolutionary game. Hu et al. [8] studied the influence of technological innovation on the selection of two modes of closed-loop supply chain remanufacturing (dealer recycling and remanufacturing and third party recycling and remanufacturing). All of the above are studies on the impact of technological innovation of new products on remanufacturing. There are few literatures on remanufacturing technology innovation in closed-loop supply chain. Gao et al. [9] studied the influence of three different power structures with original manufacturer as leader, remanufacturer as leader and no leader on independent remanufacturer's innovation decision-making by Stackelberg game; but there is no cost-saving remanufacturing technology innovation strategy involved. Zhu et al. [10] studied the effect of original manufacturer's patent protection on remanufacturer's technological innovation strategy; neither the effect of patent licensing on the cost reduction of reproducts nor the effect of technological innovation on the cost reduction of reproducts are considered.

In recent years, a series of intellectual property rights cases related to patent infringement of reproducts have occurred in the United States, Japan and other countries, which have aroused wide attention from various countries. With the continuous development of remanufacturing, the infringement of remanufactured products has become one of the urgent problems to be solved, and it is urgent to improve the protection system of product patent rights. Wang [11] analyzed the optimal strategy and coordination mechanism of closed-loop supply chain members under the condition of centralized decision and decentralized decision by game theory. Wen et al. [12] considered patent protection environment, and analyzed the pricing decisions of the original manufacturer, the two manufacturers and the retailer under centralized and decentralized decision-making considering patent protection. Shen et al. [13] analyzed the optimal decision of original manufacturers and remanufacturers in the case of single cycle with no recycling quantity limit and two cycles with recycling quantity limit by game theory in the patent perfect market. The above literature studies the effect of patent protection on closed-loop supply chain system members, but does not cover the effect of patent protection on remanufacturing technology innovation.

Traditional game theory of complete rationality hypothesis requires participants are completely rational, and it runs under the condition of complete information. However, in reality, the participants of complete rationality and the condition of complete information is difficult to achieve. Evolutionary game is different from the traditional game theory, and does not require participants are completely rational, also does not require the condition of complete information. Therefore, it is more rationality that we analysis the strategy choices of participants by evolutionary game. In view of this, this paper makes decisions on patent licensing of original manufacturers and remanufacturing technology innovation of independent remanufacturers in the closed-loop supply chain. This paper discusses the strategy selection game between original manufacturers and independent remanufacturers by evolutionary game method with the considering of a dual impact on reducing reproduct's cost cause of patent licensing and technological innovation. And we find out the path dependence of independent remanufacturers choosing remanufacturing technology innovation, and then put forward some suggestions for remanufacturing technology innovation.

2. Notations and model assumptions
In this paper, we study a remanufacturing closed-loop supply chain system composed of an original manufacturer and an independent manufacturer. The original manufacturer is responsible for the
production and sale of new products (i.e., the original manufacturer plays the role of the new product distributor at the same time), the independent manufacturer is responsible for the production and sale of reproducts (i.e., the independent manufacturer plays the role of the reproducts distributor at the same time).

2.1. Notations

\[ p_2/p_6 \in [0,1] \]: Market clearing price for new product/reproduct
\[ q_2/q_6 \in [0,1] \]: Output of new product/reproduct
\[ c_2 \in (0,1) \]: Production cost of new product
\[ c_6 \in (0,c_2) \]: Production cost of reproduct
\[ s \in (0,c_6) \]: Cost savings on reproduct production under patent licensing
\[ f \in (0,p_6) \]: The unit license fee authorized by the original manufacturer to an independent remanufacturer for the remanufacturing of patented products
\[ x \in [0,1] \]: Output level of remanufacturing technology innovation
\[ v \in [0,1] \]: The willingness of consumers to pay for new product
\[ r \in (0,c_6) \]: The maximum cost savings of reproduct by remanufacturing technology innovation
\[ \theta \]: The discount of consumers’ willingness to pay for reproduct
\[ k \in (0,\infty) \]: Investment cost coefficient of technology innovation

2.2. Model assumptions

Hypothesis 1: The new products produced by the original manufacturer in this paper are all patented products.
Hypothesis 2: The innovation of remanufacturing technology can reduce the production cost of reproducts, set the reduced production cost as \( r_x \).
Hypothesis 3: The potential market demand is 1, and \( v \) obeys the uniform distribution on \([0, 1]\). The utility of consumer buying new products is \( v - p_2 \), and the utility of consumer buying reproducts is \( \theta v - p_6 \). When carrying out remanufacturing technology innovation, since remanufacturing technology innovation can improve the performance of reproducts, consumers’ willingness to pay for remanufactured products also increases correspondingly, hence the utility of consumer buying reproduct changes to \( \theta(v + x) - p_6 \).
Hypothesis 4: The investment cost of remanufacturing technology innovation of independent remanufacturers is closely related to the innovation output level. Without loss of generality, innovation investment cost is a convex function of innovation output level, set as \( \frac{k}{2}x^2 \).
Hypothesis 5: The quantity of recycled waste products is sufficient and the output of remanufactured products is not limited by it.
Hypothesis 6: A product life cycle is defined as a cycle in which consumers buy at most one product (new product or reproduct) per cycle, and both the new product and the reproduct can be used for one cycle.
Hypothesis 7: Both the original manufacturer and the independent remanufacturer are risk neutral.

3. Establishment and analysis of evolutionary game model

This section constructs a two-player game consisting of an original manufacturer and an independent reproducer, set it as \( G \). \( N=\{1,2\} \) represents the set of players participating in the game, where 1 represents the original manufacturer and 2 represents the independent remanufacturer. The original manufacturer’s strategy set is \( S_1=\{\text{patent license, no patent license}\} \), and the remanufacturer’s strategy set is \( S_2=\{\text{remanufacturing technology innovation, no remanufacturing technology innovation}\} \). The game’s strategy space is the cartesian product of all the game party’s strategy sets, i.e. \( S=S_1 \times S_2=\{(\text{patent license, remanufacturing technology innovation}), (\text{patent license, no remanufacturing technology innovation}), (\text{no patent license, remanufacturing technology innovation}), (\text{no patent license, no remanufacturing technology innovation})\} \).
remanufacturing technology innovation). Any of $i \in \mathbb{N}$, set the utility function of player $i$ is $U_i$, then this game can be represented as $G = [\mathbb{N}, S, \{U_i\}_{i \in \mathbb{N}}]$.

3.1. Inverse demand function

Based on the theory of individual rationality and incentive compatibility, it needs to satisfy when consumer buys new product:

$$\begin{cases} 
\nu - p_n > 0 \\
\nu - p_n > \theta(\nu + x) - p_r 
\end{cases}$$

Then it can be calculated as follows:

$$\begin{cases} 
\nu > p_n \\
\nu > \frac{p_n - p_r + \theta x}{1 - \theta}
\end{cases}$$

It needs to satisfy when consumer buys reproduct:

$$\begin{cases} 
\theta(\nu + x) - p_r > 0 \\
\theta(\nu + x) - p_r > \nu - p_n 
\end{cases}$$

Then it can be calculated as follows:

$$\begin{cases} 
\nu > \frac{p_r}{\theta} - x \\
\nu < \frac{p_n - p_r + \theta x}{1 - \theta}
\end{cases}$$

When $p_r < \theta(p_n + x)$, $p_n < \frac{p_n - p_r + \theta x}{1 - \theta}$, $\frac{p_n - p_r + \theta x}{1 - \theta} > \frac{p_r}{\theta} - x$. We know $\nu$ follows a uniform distribution on $[0,1]$ from hypothesis 3, hence the market demand for the new product is

$$q_n = \int_{\frac{p_n - p_r + \theta x}{1 - \theta}}^{1} dv = 1 - \frac{p_n - p_r + \theta x}{1 - \theta}, \quad (1)$$

The market demand for the reproduct is

$$q_r = \int_{\frac{p_n - p_r + \theta x}{1 - \theta}}^{0} dv = \frac{p_n - p_r + \theta x}{1 - \theta}, \quad (2)$$

When $p_r > \theta(p_n + x)$, $p_n > \frac{p_n - p_r + \theta x}{1 - \theta}$, $\frac{p_n - p_r + \theta x}{1 - \theta} < \frac{p_r}{\theta} - x$. We know $\nu$ follows a uniform distribution on $[0,1]$ from hypothesis 3, hence the market demand for the new product is

$$q_n = \int_{p_n}^{1} dv = 1 - p_n,$$

The market demand for the reproduct is

$$q_r = 0.$$

This paper studies the mutual influence between the strategy of original manufacturer’s patent licensing and the strategy of independent remanufacturer’s remanufacturing technology innovation. It does not consider the monopoly of new products in the exclusive market, so it only considers the situation that new products and remanufactured products exist in the market at the same time. Equation (1) and equation (2) are solved for (3) and (4):
\[ p_n = 1 - q_n - \theta q_r. \]  \hspace{1cm} (3)

\[ p_r = \theta(1 - q_n - q_r + x). \]  \hspace{1cm} (4)

3.2. **Payoff matrix**

The utility of game \( G \) can be replaced by an income function, hence the payoff matrix of the two-party game between the original manufacturer and the independent remanufacturer is

| IR | Remanufacturing technology innovation | No remanufacturing technology innovation |
|----|--------------------------------------|----------------------------------------|
| OEM | Patent license                      | \[ ((p_n - c_n) q_n + f q_r, (p_r - c_{r0} + s + r x - f)) q_r k x^2 \] | \[ ((p_n - c_n) q_n + f q_r, (p_r - c_{r0} + s - f) q_r) \] |
| No patent license | \[ ((p_n - c_n) q_n (p_r - c_{r0} + r x) q_r k x^2) \] | \[ ((p_n - c_n) q_n (p_r - c_{r0}) q_r) \] |

3.3. **Establishment of evolutionary game model**

Evolutionary game theory originated from biological evolution, which is a theory combining game theory analysis and dynamic evolutionary process analysis with the research object of game players with bounded rationality [14]. In the evolutionary game model of original manufacturers and independent remanufacturers, the research objects are original manufacturers and independent remanufacturers groups that change with time. The original manufacturers and independent remanufacturers in the system dynamically adjust their strategy choices according to the final returns of each game. The model of evolutionary process mainly depends on the selection mechanism, and the replicator dynamics is a typical deterministic and nonlinear evolutionary game model based on the selection mechanism [15, 16].

Suppose in the evolutionary game between original manufacturer and independent remanufacturer, original manufacturer’s intention to choose patent license, namely, the probability of patent license is \( m \), the probability of choosing no patent license is \( 1-m \); the probability of independent remanufacturers choosing to carry out remanufacturing technology innovation is \( n \), the probability of independent remanufacturers choosing to carry out no remanufacturing technology innovation is \( 1-n \). Combined with the revenue matrix in table 1, the expected revenue obtained from the original manufacturer’s patent license is

\[ E_{1Y} = n[(p_n - c_n)q_n + f q_r] + (1 - n)[(p_n - c_n)q_n + f q_r] = (p_n - c_n)q_n + f q_r, \]  \hspace{1cm} (5)

Equation (3) is substituted in equation (5),

\[ E_{1Y} = (1-q_n - \theta q_r - c_n)q_n + f q_r. \]  \hspace{1cm} (6)

The expected revenue obtained when the original manufacturer choose no patent license is

\[ E_{1N} = n[(p_n - c_n)q_n] + (1 - n)[(p_n - c_n)q_n] = (p_n - c_n)q_n, \]  \hspace{1cm} (7)

Equation (3) is substituted in equation (7),

\[ E_{1N} = (1-q_n - \theta q_r - c_n)q_n. \]

Hence the expected revenue of the original manufacturer
\[ E_1 = mE_{1Y} + (1 - m)E_{1N} = (1 - q_n - \theta q_r - c_r)q_n + mf q_r. \]  

(8)

According to the Malthusian equation [17], the original manufacturer’s replication dynamic equation is

\[ \frac{dm}{dt} = m(E_{1Y} - E_1), \]  

(9)

equation (6) and equation (8) are substituted in equation (9),

\[ \frac{dm}{dt} = m(1 - m)f. \]  

(10)

In the same way, the expected revenue of independent remanufacturer choosing technology innovation is

\[ E_{2Y} = m \left[ (p_r - c_{r0} + s + rx - f)q_r - \frac{k}{2} x^2 \right] + (1 - m) \left[ (p_r - c_{r0} + rx)q_r - \frac{k}{2} x^2 \right] \]

\[ = mq_r (s - f) + (p_r - c_{r0} + rx)q_r - \frac{k}{2} x^2, \]  

(11)

Equation (4) is substituted in equation (11),

\[ E_{2Y} = mq_r (s - f) + [\theta (1 - q_n - q_r + x) - c_{r0} + rx]q_r - \frac{k}{2} x^2, \]  

(12)

The expected revenue of independent remanufacturer choosing no technology innovation is

\[ E_{2N} = m [(p_r - c_{r0} + s - f)q_r] + (1 - m) [(p_r - c_{r0})q_r] = mq_r (s - f) + (p_r - c_{r0})q_r, \]  

(13)

Equation (4) is substituted in equation (13),

\[ E_{2N} = mq_r (s - f) + [\theta (1 - q_n - q_r + x) - c_{r0}] q_r, \]

Hence the expected revenue of independent remanufacturer is

\[ E_2 = nE_{2Y} + (1 - n)E_{2N} = nx \left( rq_r - \frac{k}{2} x^2 \right) + mq_r (s - f) + [\theta (1 - q_n - q_r + x) - c_{r0}] q_r. \]  

(14)

According to the Malthusian equation [17], the remanufacturer’s replication dynamic equation is

\[ \frac{dn}{dt} = m(E_{2Y} - E_2), \]  

(15)

Equation (12) and equation (14) are substituted in equation (15),

\[ \frac{dn}{dt} = n(1 - n)(rxq_r - \frac{k}{2} x^2). \]  

(16)

Let \( F(m) = \frac{dm}{dt} \), \( F(n) = \frac{dn}{dt} \), according equation (10) and equation (16), the replication dynamic equations of the two-party evolutionary game are

\[
\begin{cases} 
F(m) = m(1 - m)f q_r \\
F(n) = n(1 - n)(rxq_r - \frac{k}{2} x^2) 
\end{cases}
\]  

(17)
3.4. Evolutionary stability analysis of strategies of original manufacturer and independent remanufacturer

Jacobian matrix local analysis method, which first appeared in literature [22], is a method to judge the stability of a system by using the characteristics of state equation solutions. This method obtains an approximate linear system by Taylor expansion of the nonlinear system’s motion equation in a sufficiently small neighborhood at the equilibrium point, and then deduces the stability of the original nonlinear system in the neighborhood according to the distribution of the eigenvalues of the linear system in the complex plane. Friedman [18] used this method to solve the evolutionary stability strategy of game differential equations. In the following part, we use Jacobian matrix local analysis method to solve the evolutionary stability strategy of the game system of seller and consumer. The Jacobian matrix of the system is obtained by equation (17),

$$J = \begin{pmatrix} \frac{\partial F(m)}{\partial m} & \frac{\partial F(m)}{\partial n} \\ \frac{\partial F(n)}{\partial m} & \frac{\partial F(n)}{\partial n} \end{pmatrix} = \begin{pmatrix} 0 & (1-2m)f_q - \frac{k}{2}x^2 \\ 0 & (1-2n)(rxq_r - \frac{k}{2}x^2) \end{pmatrix}.$$  

The determinant of the matrix J is

$$\det(J) = f_q(1-2m)(1-2n)(rxq_r - \frac{k}{2}x^2).$$

The trace of matrix J is

$$\text{tr}(J) = f_q(1-2m) + (1-2n)(rxq_r - \frac{k}{2}x^2).$$

Let $F(m) = 0$, $F(n) = 0$, we can get four equilibrium points for the system, which is $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$ respectively. We calculate the determinant and the trace of matrix J at each equilibrium point, as shown in table 2.

| equilibrium point | det(J) | tr(J) |
|------------------|--------|-------|
| $(0,0)$          | $f_q(rxq_r - \frac{k}{2}x^2)$ | $f_q + rxq_r - \frac{k}{2}x^2$ |
| $(0,1)$          | $-f_q(rxq_r - \frac{k}{2}x^2)$ | $f_q - rxq_r + \frac{k}{2}x^2$ |
| $(1,0)$          | $-f_q(rxq_r - \frac{k}{2}x^2)$ | $-f_q + rxq_r - \frac{k}{2}x^2$ |
| $(1,1)$          | $f_q(rxq_r - \frac{k}{2}x^2)$ | $-f_q - rxq_r + \frac{k}{2}x^2$ |

According to Jacobian matrix local analysis method, which equilibrium point meets $\det(J)>0$ and $\text{tr}(J)<0$, it is the local asymptotic stability point in the system of evolutionary dynamic process, corresponding to the evolutionary stability strategy ESS. At each of the equilibrium points, we solve $\det(J)>0$ and $\text{tr}(J)<0$ at the same time, and stability analysis results of equilibrium strategies of the original manufacturer and the independent remanufacturer can be obtained, as shown in table 3.

| equilibrium point | ESS conditions |
|------------------|----------------|
| $(0,0)$          | No condition is ESS |
| $(0,1)$          | No condition is ESS |
| $(1,0)$          | $x < 0$ or $x > \frac{2r_q}{k}$ |
| $(1,1)$          | $0 < x < \frac{2r_q}{k}$ |
According to table 3, (0,0) and (0,1) will not be the evolutionary stable point of game between the original manufacturer and the independent remanufacturer under any conditions. This indicates that under any conditions, no matter what initial strategy distribution is adopted by original manufacturers and independent remanufacturers, the system will not evolve to (0,0) and (0,1). According to hypothesis 1, the new product produced by the original manufacturer is a patented product, and the original manufacturer can obtain more income by choosing patent license regardless of whether the independent remanufacturer carries out remanufacturing technology innovation. Therefore, the original manufacturer choosing no patent license is not an evolutionary stability strategy. Because $0<x<1$, when \( \frac{2rq}{k} < x < 1 \), the system finally evolved to (1,0), and evolutionary stable strategy is (patent license, no remanufacturing technology innovation). It indicates that when the innovation output level is too high, the marginal cost of innovation investment is also getting higher and higher, which leads to the fact that independent remanufacturers’ remanufacturing technology innovation can no longer bring a positive increase of their income, so independent remanufacturers no longer carry out remanufacturing technology innovation. When $0<x<\frac{2rq}{k}$, the system finally evolved to (1,1), and evolutionary stable strategy is (patent license, remanufacturing technology innovation). It indicates that when the innovation output level is within a specific range, remanufacturing technology innovation can bring a positive increase of income to independent remanufacturers, so independent remanufacturers will carry out remanufacturing technology innovation.

### 4. Numerical analysis

In order to more intuitively explore the evolution trajectory of the strategies of original manufacturer and independent remanufacturer under different parameter Settings, based on the above evolutionary game model, this section conducts numerical analysis with the help of Matlab2016a software.

**Figure 1.** The evolutionary path of m when $0<x<\frac{2rq}{k}$.  
**Figure 2.** The evolutionary path of n when $0<x<\frac{2rq}{k}$.

Set $r = 0.5$, $q_r = 0.8$, $x = 0.3$, $f = 0.1$, $k = 2$. Easy to know, $0<x<\frac{2rq}{k}$. Three different initial values of m, 0.3, 0.6 and 0.9, were selected to analyze the influence of different values of n on the evolution path of m, and the numerical experimental results are shown in figure 1. The results show that: the evolutionary path of m is not affected by the values of m and n, and m eventually evolves to 1 and remains stable. That is, the original manufacturer’s patent license is an evolutionary stable strategy. Three different initial values of n, 0.3, 0.6 and 0.9, were selected to analyze the influence of different values of m on the evolution path of n, and the numerical experimental results are shown in figure 2. The results show that: the evolutionary path of n is not affected by the values of m and n, and n eventually
evolves to 1 and remains stable. That is, the independent remanufacturer’s technology innovation strategy is an evolutionary stable strategy. This is consistent with the conclusion in section 3.4.

5. Conclusions and recommendations
From the perspective of independent remanufacturers responsible for remanufacturing, this paper studies the influence of original manufacturer’s patent licensing strategy and independent remanufacturer’s technology innovation strategy on independent remanufacturers’ enthusiasm to participate in remanufacturing. We establish a two-side game composed of original manufacturer and independent remanufacturer, and explore the strategy selection mechanism of both sides, and draw the following conclusions:

For patented products, it is always beneficial for the original manufacturer to choose the patent license. For independent remanufacturers, the marginal cost of innovation investment increases with the increase of innovation output level. When the income obtained from remanufacturing technology innovation by independent remanufacturers stops increasing, the behaviour of technical innovation will stop. Through solving the evolutionary game, it can be concluded that when the remanufacturing technology innovation level $0 < x < \frac{2\nu q_r}{k}$, independent remanufacturers will choose the technology innovation strategy.

In this paper, the original manufacturer charges a fixed patent licensing fee according to the unit reproduct when it licenses the patent. In reality, there is no fixed standard for the collection of patent licensing fee. In the future, we can study the influence of different patent licensing fee modes on the strategies of original manufacturers and independent remanufacturers.

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