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Pricing Decision of Closed-Loop Supply Chain to Improve Service Level under Patent Protection

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Abstract: This paper constructs a two-level closed-loop supply chain system consisting of original parts manufacturers and parts distributors. Based on the different preferences of consumers for remanufactured parts and new parts, four combination models of patent protection and service improvement are constructed. Through comparative analysis, the impact of implementing patent protection policies by original parts manufacturers and improving service levels by parts distributors on the pricing decisions of the closed-loop supply chain is explored.Through the comparison between related models and the verification of calculation examples, it is found that (1) a manufacturer prevents the price of new products from being affected by the price of remanufactured products and upgrading of service level by introducing royalties, which reduces its loss of profit; (2) in the absence of patent protection, the manufacturer's profit decreases as the level of service increases; in the presence of patent protection, the manufacturer's profit increases as the level of service increases; (3) retailers' profits decrease after the manufacturer introduces royalties, which discourages them to improve service levels for remanufactured products; (4) as retailers raise the service level of the remanufactured products, the profits of the manufacturer and third-party manufacturers keep increasing, while the profits of the retailers first increase and then decrease.

Keywords: closed-loop supply chain; differential pricing; patent protection; service level

1 INTRODUCTION

1.1 Literature Review

In recent years, climate problems such as climate warming and melting glaciers have been emerging, and more and more people have realized the importance of environmental protection. How to maximize the utilization rate of goods to achieve the goals of energy conservation, emission reduction and environmental protection has become a topic of high concern for governments and businesses. In May 2019, the promulgation of the *Measures for the Management of End-of-Life Vehicle Recycling* indicated that China started to attach importance to the recycling of used vehicles. In 2017, China recycled 1.472 million scrapped vehicles, and this number reached 1.67 million in 2018, and was expected to approach 1.83 million in 2019 [1]. From the large number of scrapped vehicles, the usable resources should be collected and processed efficiently. Developed countries already have some experience in recycling scrapped vehicles. On the one hand, more than 90% of steel, non-ferrous materials and parts can be recycled; on the other hand, more than 50% of non-steel materials such as glass and plastic can also be recycled. Overall, the recycling of scrapped automobile resources can save 60% of energy and 70% of manufacturing materials [1]; the cost of remanufacturing with recycled old products is only 40% to 50% of that of directly manufactured products [2]. This shows that waste and scrap materials have huge utilization values, which will attract the attention of all parties whether for the purpose of environmental protection or resource conservation. Although the recycling of waste and scrap products has gradually been on the right track at this stage, companies have found in the sales process that consumers still prefer normally manufactured products much more than the remanufactured ones. In order to change this situation, the Chinese government has issued a series of policies and documents; and domestic and foreign scholars are also studying how to apply the research on supply chains to promote the recycling and sales of waste and scrap products [3-6].

Remanufactured products include general mechanical equipment, specialized mechanical equipment, office equipment, transportation equipment, and their components. The remanufactured products mentioned in this article generally refer to these categories. The main characteristics of remanufactured products are: durable products composed of standard parts, all parts can be replaced, surplus value is high, and the cost of remanufacturing is lower than surplus value. With the recycling of waste resources and the remanufacturing of products, these remanufactured products will definitely take up a share of the market from new products, affecting manufacturers' profits. In this case, manufacturers will make corresponding decisions to change the impact of remanufactured products on the market, so as to minimize the impact on their own interests. As an advanced form of circular economy, remanufacturing is different from general waste recycling. On the one hand, it requires reducing the waste of raw resources and pollution to the ecological environment, and on the other hand, it requires remanufactured products to have performance and quality no less than new products.

A closed-loop supply chain refers to a complete network structure composed of upstream and downstream members involved in product production, sales, and return to the merchant. Its characteristics are closure, uncertainty, and system complexity. Its cooperation modes include manufacturer recycling mode, retailer recycling mode, and third-party recycling mode. The closed-loop supply chain increases the process of returning products from consumers to the enterprise's reprocessing and manufacturing platform, making it suitable for remanufacturing products. Factors such as information sharing, contractual constraints, and government policies can affect the profit distribution mechanism among manufacturers, channel providers, and retailers.

According to the provisions of the Patent Law, a product with patent protection must be authorized by the original manufacturer before it can be produced by a remanufacturer. Only with the right of production, can the remanufacturer carry out remanufacturing [7]. At present,

international companies attach great importance to patent protection. Cases where companies receive penalties for infringement of remanufactured products can be found everywhere, so manufacturers with patent rights have a lot of initiatives in defending their own interests.

In the process of competition between new products and remanufactured ones, many scholars at home and abroad have done in-depth research on the recycling prices, sales pricing, and distribution channels of remanufactured products.

Scholars at home and abroad have carried out extensive research on remanufactured products. Savaskan et al. [8] established three waste product recycling models to give new recycling models and explored which one had the highest efficiency. Ferry and Swaminathan [9] studied the situation of two products for more than one single cycle, and found that if a remanufactured product is very profitable, the manufacturer will increase the number of remanufactured products by adopting the strategy of "small profits but quick turnover", so as to gain more profit from the remanufactured products,providing a solid theoretical basis for reusing the remanufactured product multiple times. Majumder and Groenevelt [10] assumed that new products and remanufactured products could substitute each other, and explored the optimal decision on product pricing. Sahoo and Chakraverty [11] illustrate the Mexican Hat Wavelet Neural Network with L-BFGS optimization algorithm for simulating the recycling procedure of waste plastic in the Ocean. Cao et al. [12] classified consumers according to their preferences for traditional or direct sales channels when studying product price setting and coordination. Cao et al. [13] studied the competitiveness of remanufactured products using four closed-loop supply chain alliance structure models, and found that the quality of remanufactured products has a positive relationship with their competitiveness with the new products, that is, the higher the product quality, the greater the competitiveness. Facing the difficulty of selling remanufactured products, scholars have studied "human" factors in the promotion of sales of remanufactured products, explaining why remanufactured products can earn market share with new products. Mitra and Webster [14] studied the effects of different allocations of government subsidies on the supply chain nodes on the pricing decision and profit of the closed-loop supply chain using a two-stage model. Zhou and Yuen [15] studied how the government sets the optimal subsidy level to maximize the sales of remanufactured products with limited budgets, demonstrating the impact of limited government subsidies on remanufactured goods. Meng et al. [16] studied the optimal government consumption subsidy policy and its effect on the closed-loop supply chain, extending government subsidies to the impact on closed-loop supply chains. Hosseini-Motlagh et al. [17] study on incentivising used products collected by dealers, merchant-optimal pricing of products based on competition between two dealers for services to provide used products and price guidance from manufacturers to dealers, enriched the impact of competition between dealers on used products. Xie et al. [18] studied the different preferences of customers for different types of products and the manufacturers' efforts on remanufactured products, complementing the gap that exists between the differential impact of remanufacturing effort and preference levels on the pricing and decision making of remanufactured goods. Li and Wang [19] studied the promotion of the sales of remanufactured products from the aspects of sales efforts and government subsidies. The study found that the combination of the two measures can promote the sales of remanufactured products.

With people's increasing awareness of intellectual property, scholars introduced patent protection into the studies on closed-loop supply chains. Wang et al. [20] studied the case of the original manufacturer's profit maximising non-fixed rate to bring the model more in line with realistic market economic conditions. Sen and Tauman [21] compared two royalty models and explored the optimal decision-making and maximized profit scenarios. Wang [22] established two product pricing models and studied the impacts of patent protection on the closed-loop supply chain of remanufacturing. The results show that royalties have an impact on the recycling price and volume of waste products. Shen et al. [23] focused on studying the impact of patent protection on the decision making of closed-loop supply chains based on two government subsidy models. The research shows that manufacturers can adjust their profits through patent royalties. Xiong et al. [24] established three models to explore whether manufacturers produce remanufactured products themselves or allow a third party to do so when considering patent protection. The study shows that when the third party saves a lot of costs from waste products can it carry out production. Huang and Wang [25] studied the effects of three remanufacturing models on the pricing decision of remanufactured products in the closed-loop supply chain, with the patent licensing factor taken into account. Zhang et al. [26] considered different backgrounds for closed-loop supply chains, and at the same time, studied the patent protection factor, and the study shows that the government's allocation of rewards and penalties to products plays a key role in the pricing decision of a closed-loop supply chain. Zheng et al. [27] introduced the patent protection factor into the research of a dual-channel closed-loop supply chain, and improved the common revenue sharing contract using this method; Tang and Xu [28] conducted research on the licensing of patented products by the original manufacturer to retailers, and studied the pricing decision and coordination of remanufactured products from the direct sales channel and retail channel.

From the above literature, it can be seen that many domestic and foreign scholars have done in-depth research on the promotion of the sales of remanufactured products from the perspectives of patent protection and sales efforts, but still have not explained how manufacturers use patent protection to influence the pricing decisions of closed-loop supply chains, nor has there been any research on the relationship between improvement of service levels and patent protection. Therefore, considering the different preferences of consumers for purchases, this paper attempts to answer the following questions regarding the sales of remanufactured products under patent protection: (1) what impact does the improvement of the service level have on the sales of new and remanufactured products? (2) what impact does patent protection have on the improvement of the service level? (3) How does the manufacturer solve the problem of remanufactured

products taking up market shares of new products using patent protection?

1.2 Problem Description and Modelling

The three-level closed-loop supply system consists of three players: the manufacturer, the third-party remanufacturer, and the retailer. The manufacturer produces new products only, while the third-party remanufacturer recycles and remanufactures used parts. If the remanufactured product is subject to patent protection, the remanufacturer must pay royalty of a certain amount to the manufacturer for each unit remanufactured. The retailer sells both new and remanufactured products. Since customers have different preferences for new products and remanufactured ones, to promote the sales of remanufactured products, the retailer may improve the service level of remanufactured products by providing additional after-sales services such as extended after-sales service time and free-of-charge replacement of remanufactured products damaged during the warranty period.

Service level refers to the ability of the supply chain to provide customers with the required products or services within a specific time frame. Generally speaking, a high level of service means faster order fulfilment speed, which also requires higher inventory and more effective and flexible production plans.

This article mainly studies the impact of improving service levels under patent protection on closed-loop supply chain pricing decisions. The model construction process is as follows.

Let the market demand of a product be q, the customers' willingness θ to pay for the new product obey the uniform distribution of [0, q], and the customers' willingness to pay for the remanufactured product be $\alpha\theta$, and $\alpha\in(0,\ 1)$ represents the customers' preference coefficient for the remanufactured product. When the service level is not improved, the utility functions of the customer purchasing a unit of the new product and the remanufactured product are $U_n=\theta-p_n$ and $U_k=\alpha\theta-p_k$, respectively. The demand functions of the new product and the remanufactured one are $q_n=q-\frac{p_n-p_k}{1-\alpha}$, and $q_k=\frac{\alpha p_n-p_k}{\alpha(1-\alpha)}$, respectively. When the service level is improved, the utility functions are $U_n=\theta-p_n$ and $U_k=\alpha\theta-p_k+\alpha^2 t$, and the sales functions are $q_n=q-\frac{p_n-p_k+\alpha^2 t}{1-\alpha}$ and $q_k=\frac{\alpha p_n-p_k+\alpha^2 t}{(1-\alpha)\alpha}$.

Assumptions:

1. There are sufficient used parts for retail, and there is no shortage.
2. The number of remanufactured products that can be produced per unit of used parts can be determined.
3. From the perspective of product quality, there is no difference between new products and remanufactured products.

The symbols involved in this paper and their meanings are listed in the table below.

Table 1 Symbol description

Symbol	Meaning
π_i^j	Profit in various modes
q_n^j ; q_k^j	Sales of parts in various modes
p_n^j ; p_k^j	Wholesale prices of parts in various modes
w_n^j ; w_k^j	Wholesale prices of parts
c_n^j ; c_k^j	Part manufacturing cost
f	Royalty
β	Unit recovery cost of used parts
α	Customers' preference for remanufactured products
b	Service cost factor

Note: when i is m, l, or r, it represents the manufacturer, the third-party remanufacturer, or the retailer, respectively; when j is *UN*, *US*, *RN*, or *RS*, it represents the model with no patent protection and no improved service level, the one with no patent protection but improved service level, the one with patent protection but no improved service level and the one with patent protection and improved service level; n represents the new product; k the remanufactured product; * the optimal situation; and the feasibility of the remanufacturing recycling activities $0\le\beta\le c_n-c_k$, considering customers' different preference for parts, the wholesale and retail prices of remanufactured parts are lower than those of new parts.

2 MODELING

2.1 Scenario where the Remanufactured Product is Subject to no Patent Protection, with no Improved Service Level (Model UN)

When the manufacturer has no awareness of patent protection and does not recognize the value of remanufactured products, this is the best period for the development of a third-party remanufacturer, who recycles the used parts and remanufactures products. At this point, the wholesale price of the remanufactured product has been determined by the manufacturer and the third-party remanufacturer, and the retailer determines the retail prices of the new product and the remanufactured one based on the wholesale price.

The profit functions for the manufacturer, the third-party remanufacturer and the retailer are as follows:

$$\pi_m^{UN}=q_n\times(w_n-c_n) \tag{1}$$

$$\pi_l^{UN}=q_k\times(w_k-c_k-\beta) \tag{2}$$

$$\pi_r^{UN}=q_n\times(p_n-w_n)+q_k\times(p_k-w_k) \tag{3}$$

At this time, the optimal decision of the closed-loop supply chain is as follows:

$$p_k^{UN*}=\frac{5q\alpha-2q\alpha^2+2\beta+2c_k+\alpha c_n}{8-2\alpha} \tag{4}$$

$$p_n^{UN*}=\frac{6q-3q\alpha+\beta+c_k+2c_n}{8-2\alpha} \tag{5}$$

$$w_k^{UN*}=-\frac{q\alpha-q\alpha^2+2\beta+2c_k+\alpha c_n}{-4+\alpha} \tag{6}$$

$$w_n^{UN*} = -\frac{2q - 2q\alpha + \beta + c_k + 2c_n}{-4 + \alpha} \tag{7}$$

The sales volume and profit under the optimal decision are as follows:

$$q_n^{UN*} = \frac{2q - 2q\alpha + \beta + c_k + (-2 + \alpha)c_n}{2(-4 + \alpha)(-1 + \alpha)} \tag{8}$$

$$q_k^{UN*} = \frac{q\alpha - q\alpha^2 + (-2 + \alpha)(c_k + \beta) + \alpha c_n}{2(-4 + \alpha)(-1 + \alpha)\alpha} \tag{9}$$

$$\pi_m^{UN*} = \frac{(2q - 2q\alpha + \beta + c_k + (-2 + \alpha)c_n)^2}{2(4 - \alpha)^2(1 - \alpha)} \tag{10}$$

$$\pi_l^{UN*} = \frac{(q\alpha - q\alpha^2 - 2\beta + \alpha\beta + (-2 + \alpha)c_k + \alpha c_n)^2}{2(4 - \alpha)^2(1 - \alpha)\alpha} \tag{11}$$

$$\begin{aligned}\pi_r^{UN*} &= \frac{-2q - q\alpha + \beta + c_k + 2c_n}{2(-4 + \alpha)} \\ &\times \frac{2q(1 - \alpha) + \beta + c_k + (-2 + \alpha)c_n}{2(-4 + \alpha)(-1 + \alpha)} \\ &+ \frac{-3q\alpha + 2(\beta + c_k) + \alpha c_n}{2(-4 + \alpha)} \\ &\times \frac{q\alpha - q\alpha^2 + (-2 + \alpha)(c_k + \beta) + \alpha c_n}{2(-4 + \alpha)(-1 + \alpha)\alpha}\end{aligned} \tag{12}$$

2.2 Scenario where the Remanufactured Product is Subject to no Patent Protection, with Improved Service Level (Model US)

Since consumers prefer new products more than remanufactured ones, consumers' demand for remanufactured products is smaller than that for new products [12]. Therefore, retailers offer additional services for remanufactured products, such as extending the warranty period or providing free-of-charge replacement during the warranty period, to improve consumers' preference for remanufactured products and increase their sales and market shares.

The profit functions for the manufacturer, the third-party remanufacturer, and the retailer are as follows

$$\pi_m^{US} = q_n \times (w_n - c_n) \tag{13}$$

$$\pi_l^{US} = q_k \times (w_k - c_k - \beta) \tag{14}$$

$$\pi_r^{US} = q_n \times (p_n - w_n) + q_k \times (p_k - w_k) - \frac{1}{2}bt^2 \tag{15}$$

At this time, the optimal decision of the closed-loop supply chain is as follows:

$$w_n^{US*} = -\frac{2q(1 - \alpha) - t\alpha^2 + \beta + c_k + 2c_n}{-4 + \alpha} \tag{16}$$

$$w_k^{US*} = -\frac{(q\alpha + 2t\alpha^2)(1 - \alpha) + 2(\beta + c_k) + \alpha c_n}{-4 + \alpha} \tag{17}$$

$$p_k^{US*} = \frac{q\alpha(5 - \alpha) + 2t\alpha^2(3 - \alpha) + 2(\beta + c_k) + \alpha c_n}{8 - 2\alpha} \tag{18}$$

$$p_n^{US*} = \frac{3q(2 - \alpha) - t\alpha^2 + \beta + c_k + 2c_n}{8 - 2\alpha} \tag{19}$$

The sales volume and profit under the optimal decision are as follows:

$$q_n^{US*} = \frac{2q(1 - \alpha) - t\alpha^2 + \beta + c_k + (-2 + \alpha)c_n}{2(-4 + \alpha)(-1 + \alpha)} \tag{20}$$

$$\pi_m^{US*} = \frac{(2q - 2q\alpha - t\alpha^2 + \beta + c_k + (-2 + \alpha)c_n)^2}{2(4 - \alpha)^2(1 - \alpha)} \tag{21}$$

$$\begin{aligned}\pi_l^{US*} = \frac{(q\alpha - q\alpha^2 + 2t\alpha^2 - t\alpha^3 - 2\beta}{+\alpha\beta + (-2 + \alpha)c_k + \alpha c_n)^2}{2(4 - \alpha)^2(1 - \alpha)\alpha}\end{aligned} \tag{22}$$

$$\begin{aligned}\pi_r^{US*} &= \frac{2q - 2q\alpha - t\alpha^2 + \beta + c_k + (-2 + \alpha)c_n}{2(-4 + \alpha)(-1 + \alpha)} \\ &\times \frac{-2q - q\alpha - t\alpha^2 + \beta + c_k + 2c_n}{2(-4 + \alpha)} \\ &+ \frac{q\alpha - q\alpha^2 + 2t\alpha^2 - t\alpha^3 - 2\beta + \alpha\beta + (-2 + \alpha)c_k + \alpha c_n}{2(-4 + \alpha)(-1 + \alpha)\alpha} \\ &\times \frac{-3q\alpha - 2t\alpha^2 + 2\beta + 2c_k + \alpha c_n}{2(-4 + \alpha)} - \frac{1}{2}bt^2\end{aligned} \tag{23}$$

2.3 Scenario where the Remanufactured Product is Subject to Patent Protection, with no Improved Service Level (Model RN)

Nowadays, people's legal awareness keeps increasing. Therefore, when the original manufacturer finds the market share of the new product is being taken up by the remanufactured one, the manufacturer will charge royalties to the third-party remanufacturer to control the impact of the remanufactured product on the new product in the market and reduce its loss of profits. The game process of the members in the supply chain is as follows: first, the manufacturer determines the wholesale price and royalty of the new product; then, the third-party remanufacturer determines the wholesale price of the remanufactured product, and finally, the retailer determines the retail price of the product.

The profit functions for the manufacturer, the third-party remanufacturers, and the retailer are as follows:

$$\pi_m^{RN} = q_n \times (w_n - c_n) + q_k \times f \tag{24}$$

$$\pi_l^{RN} = q_k \times (w_k - c_k - \beta - f) \tag{25}$$

$$\pi_r^{RN} = q_n \times (p_n - w_n) + q_k \times (p_k - w_k) \tag{26}$$

At this time, the optimal decision of the closed-loop supply chain is as follows:

$$f^{RN*} = \frac{1}{2}(q\alpha - \beta - c_k) \ . w_n^{RN*} = \frac{1}{2}(q + c_n) \tag{27}$$

$$w_k^{RN*} = \frac{1}{4}(2q\alpha + \beta + c_k + \alpha c_n) \tag{28}$$

$$p_n^{RN*} = \frac{1}{4}(3q + c_n) \ p_k^{RN*} = \frac{1}{8}(6q\alpha + \beta + c_k + \alpha c_n) \tag{29}$$

The product demand and profit under the optimal decision are as follows:

$$q_n^{RN*} = -\frac{2q - 2q\alpha + \beta + c_k + (-2+\alpha)c_n}{8(-1+\alpha)} \tag{30}$$

$$q_k^{RN*} = \frac{\beta + c_k - \alpha c_n}{8(-1+\alpha)\alpha} \tag{31}$$

$$\pi_m^{RN*} = \frac{(q\alpha - \beta - c_k)(\beta + c_k - \alpha c_n)}{16(-1+\alpha)\alpha} - \frac{(q - c_n)(2q - 2q\alpha + \beta + c_k + (-2+\alpha)c_n)}{16(-1+\alpha)} \tag{32}$$

$$\pi_l^{RN*} = -\frac{(\beta + c_k - \alpha c_n)^2}{32(-1+\alpha)\alpha} \tag{33}$$

$$\pi_r^{RN*} = -\frac{(2q - 2q\alpha + \beta + c_k + (-2+\alpha)c_n)(q - c_n)}{32(-1+\alpha)} + \frac{(\beta + c_k - \alpha c_n)(2q\alpha - \beta - c_k - \alpha c_n)}{64(-1+\alpha)\alpha} \tag{34}$$

2.4 Scenario where the Remanufactured Product is Subject to Patent Protection, and with Improved Service Level (Model RS)

When the manufacturer imposes patent protection, the sales of the remanufactured product will become more difficult, and the retailer will continue to implement the strategy of improving its service level to increase the sales volume of the remanufactured product. The decision-making sequence is the same as that in model c.

The sales functions of the product are $q_n = q - \frac{p_n - p_k + \alpha^2 t}{1-\alpha}$ and $q_k = \frac{\alpha p_n - p_k + \alpha^2 t}{(1-\alpha)\alpha}$.

The profits of the manufacturer, the third party, and the retailer are:

$$\pi_m^{RS} = q_n \times (w_n - \mathrm{c}_n) + q_k \times f \tag{35}$$

$$\pi_l^{RS} = q_k \times (w_k - c_k - \beta - f) \tag{36}$$

$$\pi_r^{RS} = q_n \times (p_n - w_n) + q_k \times (p_k - w_k) - \frac{1}{2}bt^2 \tag{37}$$

At this time, the optimal decision of the closed-loop supply chain is as follows:

$$f^{RS*} = \frac{1}{2}(q\alpha + t\alpha^2 - \beta - c_k) \tag{38}$$

$$p_n^{RS*} = \frac{1}{4}(3q + c_n) \tag{39}$$

$$w_k^{RS*} = \frac{1}{4}(2q\alpha + 3t\alpha^2 + \beta + c_k + \alpha c_n) \tag{40}$$

$$p_k^{RS*} = \frac{1}{8}(6q\alpha + 7t\alpha^2 + \beta + c_k + \alpha c_n) \tag{41}$$

The product demand and profit under the optimal decision are as follows:

$$q_n^{RS*} = -\frac{2q - 2q\alpha - t\alpha^2 + \beta + c_k + (-2+\alpha)c_n}{8(-1+\alpha)} \tag{42}$$

$$q_k^{RS*} = \frac{-t\alpha^2 + \beta + c_k - \alpha c_n}{8(-1+\alpha)\alpha} \tag{43}$$

$$\pi_m^{RS*} = \frac{(q\alpha + t\alpha^2 - \beta - c_k)(-t\alpha^2 + \beta + c_k - \alpha c_n)}{16(-1+\alpha)\alpha} - \frac{(q - c_n)(2q - 2q\alpha - t\alpha^2 + \beta + c_k + (-2+\alpha)c_n)}{16(-1+\alpha)} \tag{44}$$

$$\pi_l^{RS*} = -\frac{(-t\alpha^2 + \beta + c_k - \alpha c_n)^2}{32(-1+\alpha)\alpha} \tag{45}$$

$$\pi_r^{RS*} = -\frac{(2q - 2q\alpha - t\alpha^2 + \beta + c_k + (-2+\alpha)c_n)(q - c_n)}{32(-1+\alpha)} + \frac{(-t\alpha^2 + \beta + c_k - \alpha c_n)(2q\alpha + t\alpha^2 - \beta - c_k - \alpha c_n)}{64(-1+\alpha)\alpha} - \frac{1}{2}bt^2 \tag{46}$$

3 COMPARATIVE ANALYSIS

3.1 Analysis of the Impact of Improved Service Level on the Supply Chain Without Patent Protection

In order to explore whether the additional services provided by the retailer for remanufactured products can mitigate the difficulty in selling remanufactured products, and how it affects the closed-loop supply chain system and the optimal decisions and profits of the members, 2.1 was compared with 2.2, and the following conclusions were drawn.

Conclusion 1: In the absence of patent protection, whether there are additional services for the remanufactured product or not, the price of the product and its sales volume have the following relationship; it can be seen that when there is no patent protection, new products have price and sales advantages without improving service levels; remanufacturing products and improving services have a price advantage.

$$\begin{aligned} &w_n^{US*} < w_n^{UN*} \quad p_n^{US*} < p_n^{UN*} \quad w_k^{US*} < w_k^{UN*} \\ &p_k^{US*} < p_k^{UN*} \quad q_n^{US*} < q_n^{UN*} \quad q_k^{US*} < q_k^{UN*} \end{aligned} \tag{47}$$

$$\left(q_n^{US*} + q_k^{US*}\right) - \left(q_n^{UN*} + q_k^{UN*}\right) > 0 \tag{48}$$

Proof:

$$\begin{aligned} w_k^{US*} - w_k^{UN*} &= \frac{t(-2+\alpha)\alpha^2}{-4+\alpha} > 0 \\ w_n^{US*} - w_n^{UN*} &= \frac{t\alpha^2}{-4+\alpha} < 0 \end{aligned} \tag{49}$$

$$\begin{aligned} p_k^{US*} - p_k^{UN*} &= \frac{t(-3+\alpha)\alpha^2}{-4+\alpha} > 0 \\ p_n^{US*} - p_n^{UN*} &= \frac{t\alpha^2}{2(-4+\alpha)} < 0 \end{aligned} \tag{50}$$

$$\begin{aligned} q_n^{US*} - q_n^{UN*} &= -\frac{t\alpha^2}{2\left(4-5\alpha+\alpha^2\right)} < 0 \\ q_k^{US*} - q_k^{UN*} &= -\frac{t(-2+\alpha)\alpha}{2(-4+\alpha)(-1+\alpha)} > 0 \end{aligned} \tag{51}$$

$$(q_n^{US*} + q_k^{US*}) - (q_n^{UN*} + q_k^{UN*}) = \frac{t\alpha}{4-\alpha} > 0 \tag{52}$$

Corollary 1:

Faced with low consumer recognition and small market shares of the remanufactured product, the retailer may increase its competitiveness by improving the service level for the remanufactured product in the absence of patent protection, thereby changing the market status of the product. This will not only increase the retail price of the remanufactured product, but also increase the wholesale price, and the sales volume of the remanufactured product will also increase, indicating that the improvement of services for the remanufactured product effectively solves the initial difficulty in sales. With the improvement of the service level for the remanufactured product, the recognition of the remanufactured product by consumers increases, leading to a decrease in the market share of the new product, and the manufacturer can only adopt the strategy of price reduction to increase the competitiveness of the new product. Therefore, the price and sales volume of the new product are both reduced when the service level is improved. Despite the smaller market of the new product with the retailer improving the service level, the overall market of the new product and the remanufactured one has expanded.

Conclusion 2: in the absence of patent protection, with the improved service level for the remanufactured product, the impacts on the manufacturer, the third-party remanufacturer, and the retailer are as follows:

$\pi_m^{US*} < \pi_m^{UN*}$, and $\pi_l^{US*} > \pi_l^{UN*}$, and the values of π_l^{US*} and π_l^{UN*} are related to the demand of the product, the recovery price and cost of the remanufactured product, and the cost of the new product, etc.

Proof:

As $w_n^{US*} - w_n^{UN*} < 0$ and $q_n^{US*} - q_n^{UN*} < 0$, the profit of the manufacturer producing the original product must decrease, and accordingly, $\pi_m^{US*} < \pi_m^{UN*}$.

Similarly, $w_k^{US*} - w_k^{UN*} > 0$ and $q_k^{US*} - q_k^{UN*} > 0$. The profit of the third-party remanufacturer who produces the remanufactured product must rise - $\pi_l^{US*} > \pi_l^{UN*}$.

The change in the retailer's profit after the service level for the remanufactured product is improved is proved as follows:

$$\pi_l^{US*} - \pi_l^{UN*} = \frac{t\begin{pmatrix} 32bt - 48bt\alpha + 18bt\alpha^2 \\ -2bt\alpha^3 + 8q\alpha^2(\alpha-1) - 4t\alpha^3 + 3t\alpha^4 \\ +2(4-3\alpha)\alpha(c_k+\beta) - 2\alpha^3 c_n \end{pmatrix}}{4(-4+\alpha)^2(-1+\alpha)} \tag{53}$$

There exist two critical values:

$$b_1 = \frac{-4\alpha^3 + 3\alpha^4}{-32 + 48\alpha - 18\alpha^2 + 2\alpha^3} \quad .$$

$$t_1 = \frac{8q\alpha^2 - 8q\alpha^3 - 8\alpha\beta + 6\alpha^2\beta - 8\alpha c_k + 6\alpha^2 c_k + 2\alpha^3 c_n}{32b - 48b\alpha + 18b\alpha^2 - 4\alpha^3 - 2b\alpha^3 + 3\alpha^4} \tag{54}$$

When $0 < b < b_1$, $\pi_l^{US*} > \pi_l^{UN*}$

$b > b_1$, and $t < t_1$, $\pi_l^{US*} > \pi_l^{UN*}$; $t > t_1 \pi_l^{US*} < \pi_l^{UN*}$

Corollary2:

In the absence of patent protection, the retailer can hardly increase the profit from the remanufactured product and promote the sales of the remanufactured product by improving the service level, but the increase in such sales will reduce the profit of the manufacturer. When the cost of the service level improvement is low, improving the service level to the extent of $0 < t < t_1$, the retailer's profit will decrease. When the service level is above the critical value t_1, the higher the service level is, the greater the retailer's profit will be. When the cost of the service level improvement is high, there is a maximum value t_1 for the improved service level. When the service level exceeds this certain value, the profit of the retailer will be lower than that before the service level is improved. Therefore, only focusing on improving the service level does not definitely bring about an increase in profits.

3.2 Analysis of the Impact of the Improved Service Level on the Supply Chain in the Presence of Patent Protection

In order to explore how the improved service level of the retailer affects the profit of the closed-loop supply chain system and the optimal decision of the members, 2.3 was compared with 2.4, and the following conclusions were drawn:

Conclusion 3: In the presence of patent protection, whether there are additional services for the remanufactured product or not, the price of the product and the sales volume have the following relationship:

$$w_n^{RS*}=w_n^{RN*}.p_n^{RS*}=p_n^{RN*}.w_k^{RS*}>w_k^{RN*}p_k^{RS*}>p_k^{RN*}$$
$$q_k^{RS*}>q_k^{RN*}f^{RS*}>f^{RN*}(q_n^{RS*}+q_k^{RS*})>(q_n^{RN*}+q_k^{RN*})$$

The proof is as follows:

$$w_k^{RS*}-w_k^{RN*}=\frac{3t\alpha^2}{4}>0\ \ p_k^{RS*}-p_k^{RN*}=\frac{7t\alpha^2}{8}>0$$
$$q_n^{RS*}-q_n^{RN*}=\frac{t\alpha^2}{8(-1+\alpha)}<0$$
$$q_k^{RS*}-q_k^{RN*}=\frac{t\alpha}{8-8\alpha}>0\ \ f^{RS*}-f^{RN*}=\frac{t\alpha^2}{2}>0$$
$$(q_n^{RS*}+q_k^{RS*})-(q_n^{RN*}+q_k^{RN*})=\frac{t\alpha}{8}>0$$

Corollary3:

Since the cost of improving the service level for the remanufactured product is included in the cost of the remanufactured product sold, the price of the remanufactured product will increase with the improvement of service level; in order to maintain the stability of the market price of the new product, after imposing patent protection on the remanufactured product, the manufacturer no longer competes with the remanufacturer on price, and fixes the price of the new product, so the retailer's improvement of the service level will not change the wholesale price and retail price of the new product under patent protection. The manufacturer adjusts the loss of profit from the new product caused by the remanufactured product by increasing royalties, so royalties will increase with the improvement of the service level.

Conclusion 4:

In the presence of patent protection, when the service level is improved, the impacts on the profits of the manufacturer, the third-party remanufacturer, and the retailer are as follows:

$\pi_m^{RS*}>\pi_m^{RN*}$; $\pi_l^{RS*}>\pi_l^{RN*}$; the value of π_r^{RS*} and π_r^{RN*} are determined by the improvement of the service level, the cost of improving the service level, and consumers' preference for the remanufactured product. The proof is as follows:

$$\pi_m^{RS*}-\pi_m^{RN*}>-\frac{t\alpha\left(t\alpha^2-2(\beta+c_k-\alpha c_n)\right)}{16(-1+\alpha)}>0$$
$$\pi_l^{RS*}-\pi_l^{RN*}>-\frac{t\alpha\left(t\alpha^2-2(\beta+c_k-\alpha c_n)\right)}{32(-1+\alpha)}>0$$
$$\pi_r^{RS*}-\pi_r^{RN*}=$$
$$-\frac{t\left(-32bt+32bt\alpha+t\alpha^3-2\alpha\beta-2\alpha c_k+2\alpha^2c_n\right)}{64(-1+\alpha)}$$
$$b_2=-\frac{\alpha^3}{-32+32\alpha}\ \ t_2=\frac{2\alpha\beta+2\alpha c_k-2\alpha^2c_n}{-32b+32b\alpha+\alpha^3}$$

When $0<b<b_2$, $\pi_r^{RS*}-\pi_r^{RN*}>0$

When $b>b_2$, and $0<t<t_2$, $\pi_r^{RS*}-\pi_r^{RN*}>0$, and when $t>t_2$, $\pi_r^{RS*}-\pi_r^{RN*}<0$

Corollary 4:

In the presence of patent protection, improving the service level can increase the profits of the manufacturers and the third-party remanufacturer. When the cost of improving the service level is low, improving the services to the level of $0 < t < t_2$, the profit of the retailer will decrease. When the level exceeds the critical value t_2, the higher the service level is, the greater the profit of the retailer will be. When the cost of improving the service level is high, there is a maximum value t_2 for the improved service level. When the service level exceeds this certain value, the profit of the retailer will be lower than before the service level is improved. Blindly improving the service level does not necessarily bring about an increase in profits, so improving the services to a reasonable level can alleviate the difficulty in sales of the remanufactured product resulting from the increase in royalties.

3.3 Analysis of the Impact of Patent Protection on the Supply Chain

To explore how royalties affect the pricing decisions and profits of the supply chain system and its members, this section compared the situation of the remanufactured product with and without patent protection in the absence of service improvement (i.e. 2.1 vs. 2.3), and drew the following conclusions:

Conclusion 5:

When the product quantity is much greater than the product cost (the product quantity and cost are not in the same order of magnitude $q >> c_n$) (e.g. auto parts), in the absence of service improvement, the wholesale price, retail price, and sales volume of the product will exhibit the following relationship with and without patent protection imposed on the remanufactured product:

$$w_k^{RN*}>w_k^{UN*}w_n^{RN*}>w_n^{UN*}p_k^{RN*}>p_k^{UN*}p_n^{RN*}>p_n^{UN*}$$
$$q_k^{RN*}<q_k^{UN*}q_n^{RN*}<q_n^{UN*}$$
$$(q_n^{RN*}+q_k^{RN*})<(q_n^{UN*}+q_k^{UN*})$$

Proof:

Because $f^{RN*}=\frac{1}{2}(q\alpha-\beta-c_k)>0$, $q\alpha>\beta+c_k$

$$4q\alpha+2q\alpha^2>(4+\alpha)(\beta+c_k)+\alpha^2c_n$$

$$w_k^{RN*}-w_k^{UN*}=\frac{-4q\alpha-2q\alpha^2+(4+\alpha)(\beta+c_k)+\alpha^2c_n}{4(-4+\alpha)}>0$$

$$p_k^{RN*}-p_k^{UN*}=\frac{-4q\alpha-2q\alpha^2+(4+\alpha)(\beta+c_k)+\alpha^2c_n}{8(-4+\alpha)}>0$$

$$w_n^{RN*}-w_n^{UN*}=\frac{-3q\alpha+2\beta+2c_k+\alpha c_n}{2(-4+\alpha)}>0$$

$$p_n^{RN*}-p_n^{UN*}=\frac{-3q\alpha+2\beta+2c_k+\alpha c_n}{4(-4+\alpha)}>0$$

$$q_n^{RN*}-q_n^{UN*}=\frac{\alpha(-2q+2q\alpha-\beta-c_k-(-2+\alpha)c_n)}{8(-4+\alpha)(-1+\alpha)}<0$$

$$q_k^{RN*}-q_k^{UN*}=\frac{-4q\alpha+4q\alpha^2+(4-3\alpha)(\beta+c_k)-\alpha^2c_n}{8(-4+\alpha)(-1+\alpha)\alpha}<0$$

$$(q_n^{RN*}+q_k^{RN*})-(q_n^{UN*}+q_k^{UN*})=\frac{-4q\alpha-2q\alpha^2+(4+\alpha)(\beta+c_k)+\alpha^2c_n}{8(4-\alpha)\alpha}<0$$

Corollary 5:

When the quantity of the product is far greater than the product cost, with the manufacturer imposing patent protection on the remanufactured product, the wholesale price and retail price of both the new product and the remanufactured product will increase, because when the manufacturer charges royalties on the remanufactured product, the cost of the remanufactured product will increase. For this kind of product for which the cost cannot be reduced and which has a broad market, increasing the price is the only way to improve the low profit, so there appears the phenomenon that the price of the remanufactured product increases, leading to the decrease in the sales volume of the remanufactured product. In order to reduce the impact of the remanufactured product on the new product and ensure its maximum profits, the manufacturer first introduces royalties to adjust the flow of the resources in the supply chain, and then raises the price of the new product and controls it so that it is only related to the cost of the new product and its total sales volume, and no longer affected by the price of the remanufactured product. In this way, its loss of profit is minimized, and its profit is effectively guaranteed.

Conclusion 6:

The impacts on the profits of the manufacturer, the third-party remanufacturer and the retailer in the presence of patent protection without the service level improved are as follows:

$$\pi_m^{RN*}>\pi_m^{UN*};\ \pi_l^{RN*}<\pi_l^{UN*};\text{ and }\ \pi_r^{RN*}<\pi_r^{UN*}$$

Proof:

$$\pi_m^{RN*}-\pi_m^{UN*}>\frac{\alpha(8+\alpha)(q-c_n)^2}{8(-4+\alpha)^2}>0$$

$$\pi_l^{c*}-\pi_l^{a*}<-\frac{16\left(\begin{matrix}q\alpha-q\alpha^2+\\(-2+\alpha)(\beta+c_k)+\alpha c_n\end{matrix}\right)(1-\alpha)c_n}{(4-\alpha)^2}<0$$

$$\pi_r^{RN*}-\pi_r^{UN*}<\frac{-4(28-29\alpha+\alpha^2)(-q\alpha+\beta+c_k)^2}{16(-4+\alpha)^2(1-\alpha)}<0$$

Corollary 6:

When a manufacturer adopts the patent protection strategy, it improves its own profit by charging royalties to the third-party remanufacturer. In this way, the manufacturer's profit in the product market will not decrease, while the third-party remanufacturer pays royalties to the manufacturer, increasing its own total cost and thus decreasing its profit. When the profit of the third-party remanufacturer decreases, it will squeeze profit out of the retailer. So for the retailer, when the profit from the remanufactured product decreases, the total profit will also decrease. From the comparison of the scenarios with or without patent protection, it can be seen that patent protection can effectively help the manufacturer control the profit of its product and reduce its profit losses.

4 ANALYSIS OF CALCULATION EXAMPLES

In order to further illustrate and verify the main conclusions drawn in this paper, a calculation example was analyzed here, to explore the effects of the improvement of the service level t for the remanufactured product and the cost of patent protection f on the closed-loop supply chain system and its members' optimal decisions and profits. By reference to [29], the following values were assigned to these parameters of the model: $q = 1000$, $cn = 120$, $cr = 35$, $S = 8$, $\alpha = 0.5$, $A = 15$, and $b = 5$.

From the data analysis in Tab. 2, it can be seen that in the absence of patent protection, with the improvement of the service level, both the wholesale price and retail price of the new product in the market decrease, and the profit of the manufacturer decreases, while the price of and demand for the remanufactured product increase. When the service level is improved by 15 units, the market demand for the new product decreases by 1.1 units, and that for the remanufactured product increases by 3.2 units. When the service level is improved by 25 units, the market demand for the new product decreases by 1.8 units, and that for the remanufactured one increases by 5.3 units. Therefore, the total demand of the product increases, which verifies the correctness of the conclusion. When the sales of the new product are reduced by one unit, there will be 3 units of the remanufactured product flowing to the market, indicating that improving the service level is of positive significance for the reutilization of resources.

From the data analysis in Tab. 3, it can be seen that when there is patent protection, improving the service level for the manufactured product will increase the wholesale price, retail price and sales volume of the remanufactured product. It will exert no impact on the retail price and sales price of the new product, but will reduce its sales. Judging

from the reduction and increase of the market demand for the new product and the manufactured product, the total market demand increases with the improvement of the service level.

Through comparison of Tab. 2 and Tab. 3, it can be seen that there is a reverse correlation between sales price and sales volume. From the manufacturer's point of view, this is a successful strategy for safeguarding its interests, but from the perspective of resource protection advocated by the State, this is not conducive to the reuse of products and not in line with the national policy; this also shows that it is very important to possess independently developed core technologies.

Table 2 Impacts of the improved service level for the remanufactured product on the decision making of the closed-loop supply chain in the absence of patent protection

t	w_n^{US*}	w_k^{US*}	p_n^{US*}	p_k^{US*}	q_n^{US*}	q_k^{US*}
0	368.6	117.1	684.3	308.6	248.6	134.3
15	367.5	118.8	683.8	311.3	247.5	137.5
25	366.8	119.8	683.4	313.0	246.8	139.6
30	366.4	120.4	683.2	313.9	246.4	140.7

Table 3 Impacts of the improved service level for the remanufactured product on the decision making of the closed-loop supply chain in the presence of patent protection

t	w_n^{RS*}	w_k^{RS*}	p_n^{RS*}	p_k^{RS*}	q_n^{RS*}	q_k^{RS*}
0	560	277.5	780	388.8	217.5	5
15	560	280.3	780	392	216.6	6.9
25	560	282.2	780	394.2	215.9	8.1
30	560	283.1	780	395.3	215.6	8.8

It can be seen from Fig. 1 that in the absence of patent protection, the profit of the manufacturer decreases with the improvement of the service level for the remanufactured product by the retailer.

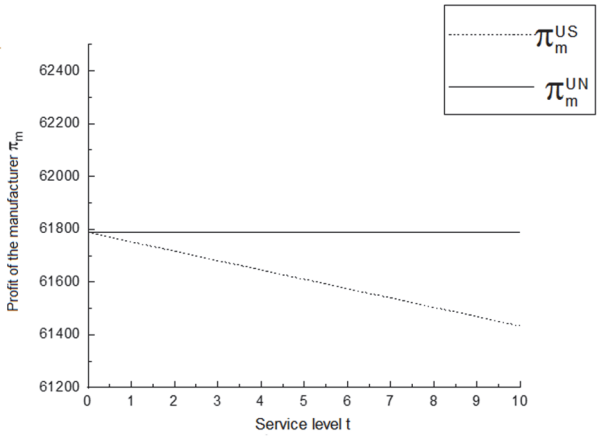

Figure 1 Impacts of the improved service level on the manufacturers' profit in the absence of patent protection

From Fig. 2, it can be seen that, in the presence of patent protection, the profit of the manufacturer increases with the improvement of the service level for the manufactured product. This is because in the absence of patent protection, the retailer increases the sales volume of the remanufactured product by improving the service level, and the manufacturer can only adopt the strategy of lowering the price to compete in the market, and even so, the manufacturer still cannot prevent the new product from losing its market; when there is patent protection, the retailer improves the service level for the remanufactured product, and the profit of the third-party remanufacturer increases, so the manufacturer will increase its own profit and make up for its loss by increasing the royalties. Therefore, when the service level is improved, two diametrically opposite situations shown in Fig. 1 and Fig. 2 may appear. Through the comparison of Figs. 1 and 2, it can be known that when the royalty is increased, the profit of the manufacturer will be greatly increased, which verifies the importance of patent protection, and also shows the necessity of possessing the core technology.

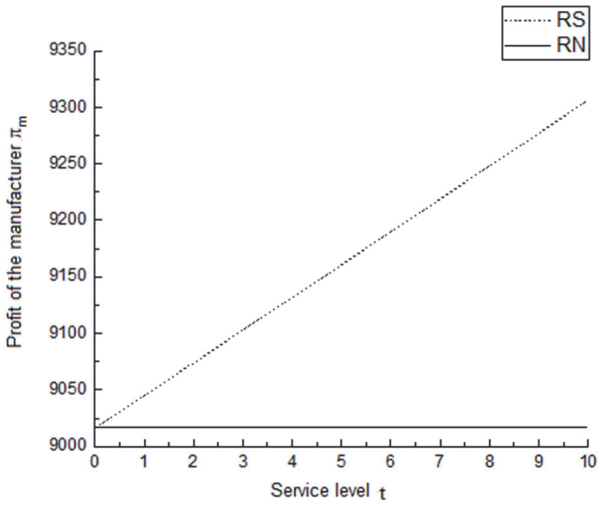

Figure 2 Impacts of the improved service level on the manufacturers' profit in the presence of patent protection

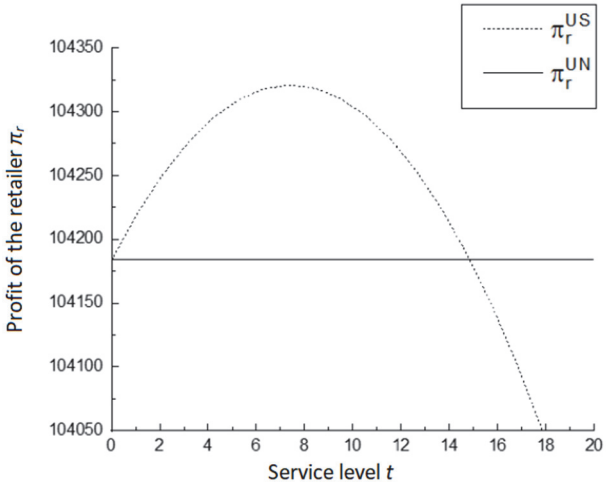

Figure 3 Impacts of the improved service level on the retailer'profit in the absence of patent protection

From Fig. 3 and Fig. 4, it can be seen that when the service level is improved, the profit of the retailer will gradually increase. But when reaching the peak, the profit will decrease with the improvement of the service level. After reaching the critical value, the more the service level is improved, the greater the profit loss will be. Therefore, it is necessary to improve the service level within a reasonable range to increase consumers' recognition of the remanufactured product so as to increase its market demand, and maximize the profit. Through comparison of Fig. 3 and Fig. 4, it can be seen that when there is patent protection, the profit of the retailer decreases, and at the same time, the range in which the retailer can effectively improve its service level is also greatly reduced. This is not

conducive to the sales of the remanufactured product, and discourages the retailer from selling the remanufactured product.

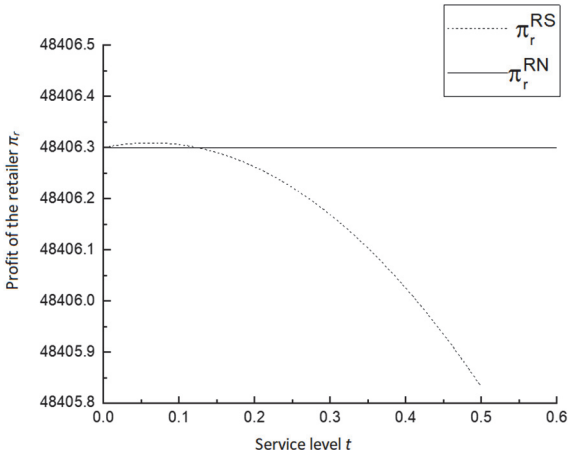

Figure 4 Impacts of the improved service level on the retailer' profit in the presence of patent protection

The relationship between service level and profit in Fig. 6 is linear, which can be expressed by the below formula:

$$\pi_l = \left(w - c_m + \Delta - f - c_0\right)\left(k + \beta c_0\right)$$

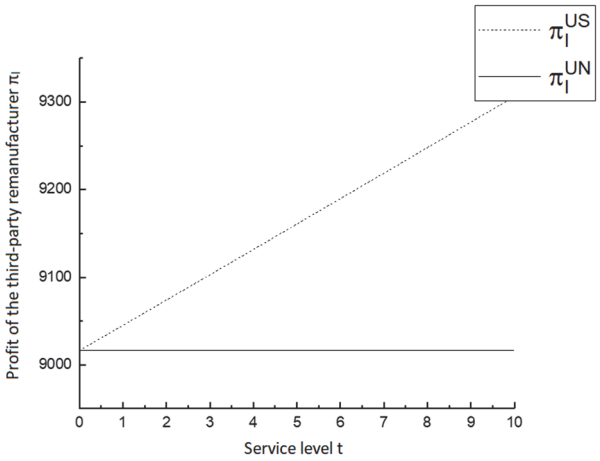

Figure 5 Impacts of the improved service level on the profit of the third-party remanufacturer in the absence of patent protection

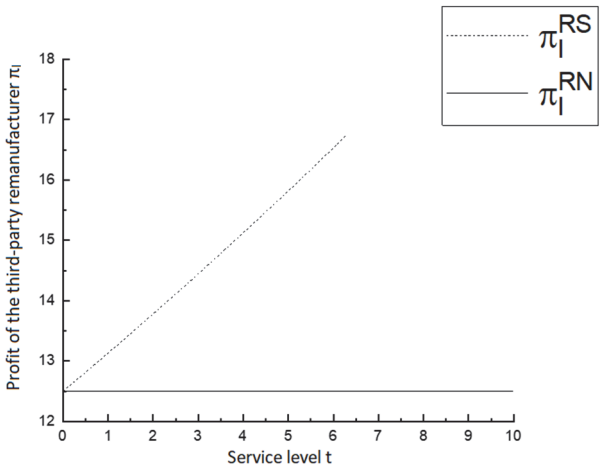

Figure 6 Impacts of the improved service level on the profit of the third-party remanufacturer in the presence of patent protection

It can be seen from Fig. 5 and Fig. 6 that the profit of the third-party remanufacturer increases with the improvement of the service level. The profit of the third-party remanufacturer in the presence of patent protection decreases sharply compared with that in the absence of patent protection, and thus the policy of patent protection maintains the interests of the manufacturer but is not conducive to the production of remanufactured products and the recycling of used materials.

Fig. 7 shows the change of the difference between the profit of the supply chain when there is patent protection and when the service level is raised than when there is no service level. It can be seen from Fig. 7 that the profit of the supply chain will gradually increase when the service level is raised, and when the peak is reached, the profit will decrease as the service level is raised, and the more the service level is raised after the critical value is reached, the greater the loss of profit of the supply chain will be; therefore, the service level should be raised within a reasonable range to increase the recognition of remanufactured products to consumers and improve market demand, so as to maximize profit.

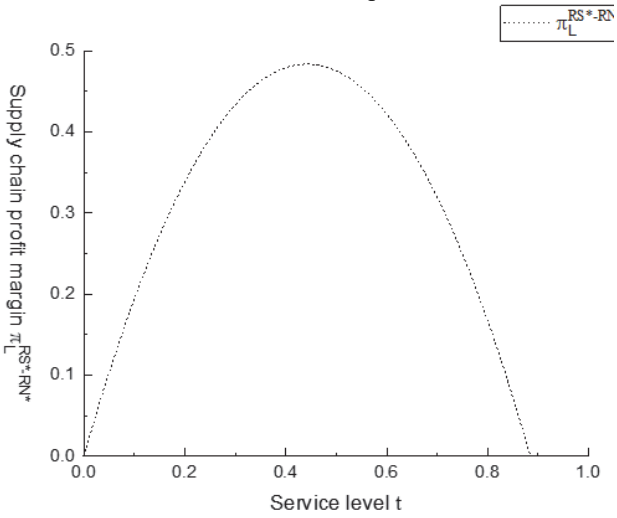

Figure 7 Impact of enhanced service levels on supply chain profit margins

5 CONCLUSIONS

This paper studies a three-level closed-loop supply chain system consisting of a manufacturer, a third-party remanufacturer, and a retailer. Four models are formulated to analyze this problem, and the following conclusions can be drawn: (1) In the absence of patent protection, the retailer improves the service level for the remanufactured product to increase the competitiveness of the remanufactured product, so both the sales volume and price of the remanufactured product increase, resulting in lower sales volume and price of the new product and thereby increasing the profit of the third-party remanufacturer, reducing that of the manufacturer, and increasing that of the retailer at a certain service level. (2) in the presence of patent protection, the manufacturer controls the wholesale price and sales price of the new product within the range of factors only related to market demand and cost through patent protection, and makes the sales price no longer affected by other factors to ensure its own profit; the retailer increases the sales volume, price and royalty of the remanufactured product by improving the service level,

and at the same time, the sales of the new product decreases, and when the profits of the manufacturer and the third-party remanufacturer increase, within the reasonable range of the service level, the profit of the retailer will also increase accordingly. (3) The manufacturer gains greater profits and maintains its own interests in the market by introducing the patent protection policy, thereby reducing the profits of the retailer and the third-party remanufacturer; the introduction of patent protection has greatly narrowed the service improvement space for the retailer, and discouraged the retailer to improve the service level for the remanufactured product, which is not conducive to the sales of the remanufactured product.(4) Within a certain range of enhanced service levels will improve the profitability of the supply chain, when enhanced service levels are too high profits will be reduced, in order to improve the overall profitability of the supply chain, therefore the service levels should be reasonably controlled.

The areas that need further improvement in this article include: (1) due to inadequate promotion by businesses and low environmental awareness among consumers, the actual recycling process of waste products may not be sufficient. Therefore, it is necessary to simultaneously study the product recycling process, (2) this article only studies the single cycle process of recycling and remanufacturing waste products, which is actually a multi cycle cyclic consumption process. Therefore, further multi cycle analysis and research on the model are needed.

Insufficient work: This paper only considers the impact of remanufactured products on the price of new products, but in the actual sales process both new and remanufactured products affect each other, and the impact between products should be improved in the next discussion, and a more accurate study can be obtained.

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