Research on Services Decision-Making in Closed-Loop Supply Chain Dominated by a Logistics Provider

Wei Li

Hunan University

Fei Chen

Hunan University

Liurui Deng (✉ purplerosed@163.com)

Hunan Normal University

Yiwen Zhao

Hunan Normal University

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Wei Li

School of Economics and Trade, Hunan University, PR China, Hunan Changsha, 410079

Hunan Key Laboratory of Logistics Information and Simulation Technology, PR China, Hunan

Changsha, 410079

Email: liweihnacs@hnu.edu.cn (W Li)

ORCID: 0000-0001-8307-4934

Fei Chen

School of Economics and Trade, Hunan University, PR China, Hunan Changsha, 410079

Hunan Key Laboratory of Logistics Information and Simulation Technology, PR China, Hunan

Changsha, 410079

Email: chenfei999@yahoo.com

Liurui Deng*(Corresponding author)

Business School, Hunan Normal University, PR China, Hunan Changsha, 410082

purplerosed@163.com

Yiwen Zhao

Business School, Hunan Normal University, PR China, Hunan Changsha, 410082

zyww1018@163.com

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Declarations of interest

None.

Declarations

Ethical Approval: The manuscript discuss supply chain issues and includes only theoretical analysis and numerical simulation of supply chains. Therefore, it does not address any ethical issues.

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Liurui Deng , Yiwon Zhao

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Research on services decision-making in closed-loop supply chain dominated by a logistics provider

Abstract: In this paper, we assume that a closed-loop supply chain consists of an original equipment manufacturer (OEM) producing new products from raw materials, a remanufacturer producing re-manufactured products from used items directly collected from customers and a logistics provider which sells and distributes two products as a monopolist in the given market. By constructing game model in which logistics provider is a leader, OEM and remanufacturer are the equal status followers, we solve chain members' optimal services decision-making. Finally, we analyze influence of service elasticities and intensities of service competition of two manufacturers on members' equilibrium decision-making.

Key words: Service, Re-manufacturing, Logistics provider, Closed-loop supply chain

1. Introduction

In recently years, the economic benefits of recycling expired products and the environmental protection have been widely recognized in the field of theory and practice. The closed-loop supply chain can recycle these products in the hands of consumers and utilize their residual value. Thierry (1995) develop a system model for closed-loop supply chain. And Guide and Van Wassenhove (2009) consider the closed loop supply chain has a wide range of business prospects. Today's supply chain systems are becoming more and more complex than just selling new products through a traditional single channel. The development of the Internet provides a new communication method for suppliers and consumers in the supply chain. More and more consumers are willing to purchase products directly through the Internet, and there are more and more manufacturers to establish online direct sales channels such as ThinkPad, HP and Dell. According to the study of China's e-commerce research center, the total online retail sales in China reached 777.8 billion yuan. At the same time, independent electronic retailers play a considerable role in the operation of the supply chain.

The hypothesis of re-manufacturing in the closed loop supply chain is mainly about ; First, the quality of new products is the same as the quality of re-manufacturing products, so the manufacturer sells both products according to the

same price; Second, although we assume that there is no difference in the quality of the two products, but in fact, consumers' willingness to pay for new products and remanufactured products is different. Therefore, the demand for these two products is different. This article is mainly referred to the three parts literature, i) The first part of the literature is about the sales channels of new products and remanufactured products in the supply chain. A large number of documents have studied the closed-loop supply chain of dual channel sales models, which is sold through a traditional retailer and an independent online retailer, Chiang et al. (2003). By establishing a price game model between manufacturers and independent retailers, we found that even if the price efficiency of other business practices is used, the introduction of direct sales channels can increase the manufacturer's profit share; Cattani et al. (2004) focus on the coordination opportunities that arise when a firm participates in both traditional and online sales channels; Chiang and Monahan (2005) point out that in most cases this dual-channel model is superior to other dual-channels, and in some cases, the cost savings caused by the flexibility of this dual channel is crucial; Cattani et al. (2006) analyze the competition of a manufacturer online sales channel and traditional sales channel; Wei-min Ma et al. (2013) focus on the impact of government sales subsidy on dual channel closed-loop supply chains. They found that consumers, manufacturers and traditional retailers are the beneficiaries of government subsidies. Therefore, government subsidies are conducive to the expansion of the closed-loop supply chain, but it is uncertain whether online retailers will benefit. ; Jiang et al. (2010) analyze the price strategy in the dual channel supply chain, the model can be used to obtain the optimal prices of new products and remanufactured products to maximize the profits of manufacturers and retailers. However, these documents do not consider the impact of services on dual channel closed-loop supply chains. ii) The second type of literature is about the impact of products and services in the supply chain, and the literature focuses on the impact of services in the game model. Cohen and Whang (1997) use the product life cycle model to study the price and service decisions of supply chain members with a manufacturer and a service provider. Tsay and Agrawal (2000) study a supply chain composed of one manufacturer and two retailers, and the

two retailers compete on product prices and services. Xia and Gilbert (2007) focus on the supply chain model of two alternative products, in which the manufacturer determines the level of service and the retailer determines the selling price. Tiaojun Xiao consider the impact of the price and service of two risk avoidance retailers under uncertain demand. Based on the manufacturer-Stackelberg game model, Wu (2012) studies the manufacturer and remanufacturer through a traditional retailer to choose their respective decisions under the conditions of price and service competition. This article has a strong correlation with Wu's research, we mainly discuss the impact of service elasticity and service competition on the equilibrium decision-making of supply chain members when there is only one sales channel, that is, the case of selling new products and re-manufacturing products through logistics providers rather than traditional retailers.

2. Model

Here we also assume that there is an original equipment manufacturer (OEM) using raw materials to produce new products in the closed-loop supply chain, a remanufacturer that makes use of recycled waste products, a logistics provider that sells and distributes the above two products. But in our model, the logistics provider is also responsible for recycling the expired waste products and delivering them to the remanufacturer. And we assume that the amount of the expired waste products recovered is equal to the amount of the remanufactured products. So the unit payment that the logistics provider gets from the original equipment manufacturer (OEM) is h , and obtains the payment from the remanufacturer as $2h$, since logistics companies distribute remanufactured products and recycle waste products. And we assume that new products and re-manufacturing are the same in performance. Logistics companies independently determine the sales price of these two products, each manufacturer produces only one product. The two manufacturers have the opportunity to increase their needs by bundled some services on the product, while logistics providers have the opportunity to increase their needs by expanding the range of services. All supply

chain members must make decisions before the sales quarter. In order to make the re-manufacturing process smoothly, the remanufacturer must first determine the degree of remanufacturing τ ($0 \leq \tau \leq 1$), τ is the proportion of recycled parts used by the unit of production in the manufacture. The two manufacturer choose their respective service levels s_j , the subscript j can be r and n , which represent remanufactured products and new products. Assume that the direct selling price of new products and remanufacture products selling products is p , the cost of production is c . The logistics provider chooses the logistics service scope l to determine the market scope. Prices and service information are published in the market before the selling season begins. We assume that the two manufacturers have sufficient production capacity to meet the quantity ordered by the logistics provider and are able to deliver a certain quantity of the goods ordered to the logistics provider before the selling season. The logistics provider is a monopolist in the market under consideration, and other products in this market and different market areas are also under consideration, but these have no effect on the demand for the two products produced. At the same time, we believe that supply chain members are independent risk neutral and profit maximizing decision makers. They choose their decisions in turn according to the logistics provider-stackelberg game model in a fair competitive environment, and each member has complete information about the other members.

2.1 Demand and profit function

Demand function

$$d_j = (\alpha_j - \beta_p p + \beta_s s_j - \gamma_s s_k) l, k \in \{r, n\} \neq j, \alpha_j, s_k, \beta_p, \beta_s, l \geq 0 \quad (2.1)$$

Original equipment manufacturer's (OEM) profit function

$$\pi_n^M = (p - c - h) d_n - \frac{m s_n^2}{2}, (p - c - h > 0) \quad (2.2)$$

$\frac{m s_n^2}{2}$ is the cost of service, and $m \geq 0$.

Reproduction product manufacturer's profit function

$$\pi_r^M = (p - c - 2h + \delta\tau)d_r - \frac{ms_r^2}{2} - \frac{b\tau^2}{2}, (p - c - 2h + \delta\tau > 0) \quad (2.3)$$

$\delta = c - cr, c(1 - \tau) + cr\tau = c - \delta\tau$, cr refers to the full re-manufacturing cost.

$\frac{b\tau^2}{2}$ is the total cost of recycling, and $b \geq 0$.

Logistics provider's profit function

$$\pi^l = \pi_r^l + \pi_n^l = (2d_r + d_n)h - \frac{m_l l^2}{2} \quad (2.4)$$

$\frac{m_l l^2}{2}$ is the logistics provider cost, h is the unit product revenue of the

logistics provider, paid by the manufacturer $h, m_l \geq 0$.

2.2 Model Solution and Analysis

The implementation of the “old for new” and “old for reuse” policies has solved the problem of shortage of raw materials in remanufacturing production to a certain extent. When there are enough old pieces, in order to encourage manufacturers to participate in remanufacturing and improve remanufacturing technology and service levels, the government also subsidizes remanufacturers to varying degrees. Such as subsidies for one-time investment in building factories, research and development, and production, etc. And, the state specifically provides freight subsidies for home appliance recycling companies, and grants fixed subsidies according to the types, specifications, and transportation distances of recycled old home appliances. The transportation distance refers to the fair distance between the actual location of the recycling enterprise and the actual location of the dismantling and processing enterprise. The specific criteria are approved and published by the local relevant authorities. Therefore, in this section we only consider the government's subsidies to the service level of remanufacturers and the service scope of logistics providers. Suppose T_{sr} is the government's subsidy rate for

the service level of remanufactured products, and T_l is the government's subsidy rate for the logistics provider's service range. Next, we study the closed-loop supply chain decision in two subsidies.

The profit function of logistics providers, remanufacturers and original equipment manufacturers is a secondary concave function of the logistics range l and service level s_r, s_n . That is, each supply chain member has the optimal choice for maximizing profits, and in competition, each member can make its own optimal strategy according to the decision of other members. In order to obtain the optimal balanced decision of the logistics range l , we use the inverse method to obtain s_n^b, s_r^b by determining the profit maximization reaction function of the original equipment manufacturer (OEM) and the remanufacturer, then substituting s_n^b, s_r^b into the logistics company to determine its profit maximization reaction function to obtain l^* , finally, substituting l^* into s_n^b, s_r^b can get a balanced decision.

2.2.1 Decision analysis of the government's subsidies for re-manufacturing services

When the government subsidizes the service level of the remanufacturer, the demand function, the profit function of the original equipment manufacturer (OEM) and the profit function of the logistics provider remain unchanged. The profit function of re-manufacture is,

$$\pi_{r1}^M = (p - c - 2h + \delta\tau)d_r - \frac{ms_r^2}{2} - \frac{b\tau^2}{2} + T_{sr}s_r \quad (4.5)$$

Remanufacturers and original equipment manufacturers determine their profit maximization reaction function, $k \neq j, j = \{r, n\}$, and obtain the first derivative

$\partial(\pi_r^M | l) / \partial s_r = 0, \partial(\pi_n^M | l) / \partial s_n = 0$, then we can obtain the following formula.

$$s_n^b = \frac{-(-p + h + c)\beta_s l}{m} \quad (4.6)$$

$$s_r^b = \frac{(p - c - 2h + \delta\tau)\beta_s l + T_{sr}}{m} \quad (4.7)$$

Logistics business determines the maximized reaction function

$l^* \in \arg \max_l (l | \tau, s_r^b, s_n^b), \partial \pi^l / \partial l = 0$, the following formula can be obtained.

$$l^* = \frac{-(2\beta_s - \gamma_s)T_{sr} + (\alpha_n + 2\alpha_r - 3\beta_p p)mh}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}, \quad (4.8)$$

Where, $\beta_s h[2(p - c - h)(\beta_s - 2\gamma_s) + 2(p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m < 0$,

Substitute formula (4.8) into formula (4.6) and formula (4.7), we can have the following function.

$$s_n^* = \frac{(-p + c + h)(2\beta_s - \gamma_s)\beta_s h T_{sr} + (-p + c + h)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s m h}{\{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m\}m}, \quad (4.9)$$

$$s_r^* = \frac{T_{sr} \{\beta_s h[2(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m\} - (p - c - 2h + \delta\tau)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s m h}{\{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m\}m} \quad (4.10)$$

Substitute formula (4.8), (4.9), (4.10) into demand function d_r^* (4.1), then we can get the equilibrium demand function d_n^* and d_r^* . Same as above, bring the formula (4.8), (4.9), (4.10) and d_n^* separately into the remanufacturer's profit function (4.5), the original equipment manufacturer's profit function (4.2) and the logistics providers profit function (4.4), then we can get the equilibrium profit $\pi_n^{M^*}, \pi_{r1}^{M^*}, \pi^{l^*}$.

Lemma 1. When $2\beta_s > \gamma_s$, s_n^* and T_{sr} are positively correlated. When $2\beta_s = \gamma_s$, s_n^* is independent of T_{sr} . And when $2\beta_s < \gamma_s$, s_n^* and T_{sr} are negatively correlated.

Corollary 1. Whether the service level of new products is positively correlated with the service subsidy of remanufactured products (T_{sr}) depends on service flexibility and service competition. If the service flexibility is greater than the level of service competition, the service level of the new product is related to the service subsidy of remanufacturing T_{sr} . In other words, government subsidies for the service of remanufactured goods will directly improve the service level of new products. Otherwise, it is negatively correlated; If the service elasticity is the same as the

service competition, the service level of the new product is not related to the service level subsidy of the remanufactured product, that is, since the government subsidizes the service of remanufactured products, the amount of subsidies has no effect on the service level of the new products. Suppose $m_l m$ is large enough to make $\beta_s h[2(p-c-h)(\beta_s-2\gamma_s)+2(p-c-2h+\delta\tau)(2\beta_s-\gamma_s)]-m_l m < 0$. Thus, the service level of remanufactured products is positively correlated with its subsidy T_{sr} . In other words, government subsidies to the service level of remanufactured goods will directly improve the service level of remanufactured goods.

When the remanufacturing service level increases with the increase of the service subsidy T_{sr} of the remanufactured goods, the demand for remanufactured products increases. There is less demand for new products because of competition in services. We assume that the prices of the two products are the same. When the service elasticity is greater than the service competition, consumers are more concerned about the service level of the purchased product at this time, and the service level of the product itself will have a greater impact on consumer demand. At this time, the original equipment manufacturer (OEM) chooses to improve the service level of the new product, which may attract more customers to buy the new product, thus increasing the demand for the new product. Therefore, under this condition, the service level of the new product will increase with the increase of the service subsidy T_{sr} of the remanufactured products. If the service elasticity is less than the service competition, the competition between the two products will be more intense. Even if the service level of the two products is not very different, it will have a great impact on the demand of consumers. When the service level of remanufactured goods increases with the higher service subsidy T_{sr} for remanufactured goods, the gap between the service level of remanufactured products and the service level of new products will increase, and the demand for remanufactured products will also increase considerably, while the demand for new products will decrease. Because when the service elasticity is less than the service competition, consumers will pay more

attention to the differences between the two products and services. At this time, OEMs are less likely to attract customers to buy new products by improving the service level of new products to reach or exceed the service level of remanufactured products. o the original equipment manufacturer may not improve or even lower the service level of the new product.

Lemma 2. When $2\beta_s > \gamma_s$, l^* and T_{sr} are positively correlated. When $2\beta_s = \gamma_s$, l^* is independent of T_{sr} . And when $2\beta_s < \gamma_s$, l^* and T_{sr} are negatively correlated.

Corollary 2. Whether the service scope of the logistics provider is positively correlated with the service level subsidy of remanufactured goods depends on the service elasticity and service competition degree. If the service elasticity is greater than the service competition degree, the service scope of the logistics provider is positively correlated with the service level subsidy of remanufactured goods. That is, government subsidies for remanufactured goods will directly expand the service scope of logistics providers, otherwise it will be negatively correlated. If the service elasticity is the same as the service competition, then the service scope of the logistics provider is not related to the service level subsidy of remanufactured products, that is, the government's subsidy of the service of remanufactured products has no effect on the service scope of the logistics provider.

When the service elasticity is greater than the degree of service competition, the increase of service subsidy T_{sr} of remanufactured products will improve the service level of new products and remanufactured products, thus increasing the demand of the two products. Then the service scope of the logistics provider may be expanded to meet the needs of customers, so at this time, the service scope of the logistics provider is positively correlated with the service level subsidy of remanufactured products. When the service elasticity is less than the service competition, the increase of service subsidy SRT for remanufactured goods will improve the service level of

remanufactured goods and thus increase the demand for remanufactured goods. However, the service level of the new product will decrease, thereby reducing its demand. The total demand for the two products may decrease, and the service scope of the logistics provider will also be reduced.

2.2.2 Decision analysis of the government's subsidies for logistics providers

When the government subsidizes the service level of logistics providers, the demand function, original equipment manufacturer's profit function, and remanufacturer's profit function remain unchanged. Logistics providers' profit function is as following function.

$$\pi^l = \pi_r^l + \pi_n^l + T_l l = (2d_r + d_n)h - \frac{m_l l^2}{2} + T_l l \quad (4.11)$$

Remanufacturers and original equipment manufacturers (OEMs) determine the profit maximization reaction function $s_j^b \in \arg \max_{s_j} \pi_j^M(s_j, s_k^b | \tau, l)$, $k \neq j$, $j = \{r, n\}$,

solve the first derivative $\frac{\partial(\pi_r^M | l)}{\partial s_r} = 0, \frac{\partial(\pi_n^M | l)}{\partial s_n} = 0$, we have

$$s_n^b = \frac{-(-p + h + c)\beta_s l}{m} \quad (4.12)$$

$$s_r^b = \frac{(p - c - 2h + \delta\tau)\beta_s l}{m} \quad (4.13)$$

Logistics providers determine the maximized reaction function maximized

$l^* \in \arg \max_l (l | \tau, s_r^b, s_n^b), \frac{\partial \pi^l}{\partial l} = 0$, we have

$$l^* = \frac{-(\alpha_n + 2\alpha_r - 3\beta_p p)h - T_l m}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}, \quad (4.14)$$

Where, $\beta_s h[2(p - c - h)(\beta_s - 2\gamma_s) + 2(p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m < 0$,

Substitute formula (4.14) into formula (4.12) and formula (4.13), We can calculate the following formula,

$$s_n^* = \frac{T_l \beta_s (p - c - h) - (p - c - h)(\alpha_n + 2\alpha_r - 3\beta_p p)h \beta_s}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m} \quad (4.15)$$

$$s_r^* = \frac{T_l \beta_s (p - c - 2h + \delta\tau) - 2(p - c - 2h + \delta\tau)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s h}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m} \quad (4.16)$$

Then substitute these formula (4.14),(4.15),(4.16) into the demand function (4.1), then we can get the equilibrium demand function d_n^* and d_r^* . Same as above, bring the formula (4.14), (4.15), (4.16) , d_n^* and d_r^* separately into the logistics providers' profit function (4.11), the original equipment manufacturer's profit function and the remanufactures' profit function, then we can get the equilibrium profit $\pi_n^{M^*}, \pi_r^{M^*}, \pi^{II^*}$.

Lemma 3. s_n^* is positively correlated with T_l , s_r^* is positively correlated with T_l .

Corollary 3. The service level of new products is positively correlated with the service subsidies of logistics provider, that is, the government subsidizes the logistics business service will directly improve the service level of new products. The service level of remanufactured products is positively correlated with the service scope subsidy of the logistics provider, that is, the government's subsidy to the service scope of the logistics provider will directly improve the service level of the remanufactured products.

When subsidizing the service scope of the logistics provider, it will indirectly reduce the costs of the two manufacturers. Because the income of the logistics provider is paid by the two manufacturers, the overall cost of the product will also be reduced. Therefore, when the product price remains unchanged, the two manufacturers can invest more in product services to improve the product's service level.

Lemma 4. l^* is positively correlated with T_l .

Corollary 4. The scope of services of logistics providers is positively correlated with their subsidies, that is, government subsidies for logistics providers will directly expand the scope of services.

When subsidizing the logistics providers' service range, it will enable logistics companies to reduce their own costs and more actively expand the scope of services in order to obtain more benefits.

3. Comparative analysis of two kinds of subsidy forms

When the government subsidize the service level of remanufactured goods and the service scope of the logistics provider, the impact on the service level of the original equipment manufacturer (OEM) and the remanufacturer and the service scope of the logistics provider is shown in the table below:

Table 1 Closed-loop supply chain decision under two kinds of subsidies

Subsidy form	Balanced decision
Government subsidies for re-manufacturing service level	$l^* = \frac{-(2\beta_s - \gamma_s)T_{sr} + (\alpha_n + 2\alpha_r - 3\beta_p p)mh}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}$ $s_n^* = \frac{(-p + c + h)(2\beta_s - \gamma_s)\beta_s h T_{sr} + (-p + c + h)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s m h}{\{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m\}m}$ $s_r^* = \frac{T_{sr}\{\beta_s h[2(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s) - m_l m] - (p - c - 2h + \delta\tau)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s m h}{\{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m\}m}$
Government subsidies for logistics providers' service scope	$l^* = \frac{-(\alpha_n + 2\alpha_r - 3\beta_p p)h - T_l m}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}$ $s_n^* = \frac{T_l \beta_s (p - c - h) - (p - c - h)(\alpha_n + 2\alpha_r - 3\beta_p p)h \beta_s}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}$ $s_r^* = \frac{T_l \beta_s (p - c - 2h + \delta\tau) - 2(p - c - 2h + \delta\tau)(\alpha_n + 2\alpha_r - 3\beta_p p)\beta_s h}{2\beta_s h[(p - c - h)(\beta_s - 2\gamma_s) + (p - c - 2h + \delta\tau)(2\beta_s - \gamma_s)] - m_l m}$

As we can see from Table 1, whether it is subsidies for remanufactured product service levels or logistics providers' service scope, the impact of the subsidy rate on the service level of new products, the service level of remanufactured products, and the service scope of logistics providers will be restricted by parameters such as service elasticity β_s , service competition γ_s , unit service cost coefficient m , and remanufacturing cost saving coefficient δ .

4. Numerical simulation and analysis

In order to study the impact of subsidies on the closed-loop supply chain more intuitively, we use numerical simulation to compare the efficiency of the two forms of subsidies. The parameter assignment in this process refers to the relevant research setting of Cheng-Han Wu. Where, we set $\alpha_n = 25$, $\alpha_r = 10$, $h = 0.1$, $c = 1.5$, $\delta = 0.5$,

$$\tau = 0.5, m = 30, m_l = 20, b = 5, p = 3, \beta_p = 5, \beta_s = 4, \gamma_s = 3.$$

4.1 Comparison of the subsidy efficiency of the two types of subsidies to the scope of logistics service providers.

Figure 4.1 The relationship between the optimal logistics provider's service scope and two kinds of subsidies

It can be seen from Figure 4.1 that both subsidies will increase as the logistics provider's optimal service range increases. And with the increase in the scope of service of logistics providers, the amount of subsidies for logistics providers' service scope will be less than the amount of subsidies for remanufactured goods' service level. And the gap will expand as the scope of logistics providers increases. It means that in order to improve the service scope of the logistics provider, it is more efficient to directly subsidize the service scope of the logistics provider than to subsidize the service level of the remanufactured products. Intuitively speaking, subsidizing the service scope of logistics providers will more directly expand the services scope of logistics providers, and the effect will be more obvious. Subsidizing the service level of remanufactured products will help to attract a wider range of consumers to purchase remanufactured products, thereby indirectly expanding the service range of logistics providers. The effect is not significant than directly subsidize the service scope of logistics providers.

4.2 Comparison of the subsidy efficiency of the two kinds of subsidy forms on the new products' service level

Figure 4.2 The relationship between optimal new products' service level and two kinds of subsidies

As shown in figure 4.2, the amount of the two subsidies will increase with the improvement of the optimal new products' service level. And with the increase of the service level of new products, the amount of subsidies for logistics providers' service scope will be less than the amount of subsidies for remanufactured goods' service level. And its gap will expand with the increase of new products' service level. This means that in order to improve the service level of new products, it will be more efficient to directly subsidize the service scope of the logistics provider than to subsidize the service level of remanufactured products.

4.3 Comparison of the subsidy efficiency of the two types of subsidies on the service level of remanufactured products.

Figure 4.3 The relationship between the optimal service level of remanufactured products and two kinds of subsidies

As shown in figure 4.3, the amount of the two subsidies will increase with the improvement of the remanufactured products' optimal service level. And with the increase of the service level of remanufactured products, the amount of subsidies for

remanufacturers will be less than the amount of subsidies for logistic providers. And its gap will expand with the increase of remanufactured products' service level. It means that in order to improve the service level of remanufactured products, it will be more efficient to directly subsidize the remanufacturers than to subsidize logistic providers. Intuitively, subsidizing the service level of remanufactured products will more directly improve the services level of remanufactured products, and the effect will be more obvious. Subsidizing the service scope of logistic providers will help to attract a wider range of consumers to purchase remanufactured products, thereby indirectly expanding the service range of logistics providers. The effect is not significant than directly subsidize the service scope of logistics providers. Subsidizing the service scope of the logistics provider will help the logistics provider to reduce the cost so as to reduce the total cost of the product. Remanufacturers can invest more in services to improve service levels with the same price, but the result is not more significant than subsidies for remanufactured products.

4.4 Comparison of subsidy efficiency of two subsidy forms on remanufactured product's output

Figure 4.4 Relationship between optimal remanufactured output and two kinds of subsidies

As shown in figure 4.4, the amount of the two subsidies will increase with the improvement of the remanufactured products' optimal service level. And as the demand for remanufactured products increases, the amount needed to subsidize remanufacturers will be less than the amount needed to subsidize logistics providers. This means that in order to increase the demand for remanufactured products, directly subsidizing remanufacturers will be more efficient than subsidizing logistics providers.

4.5 Comparison of subsidy efficiency of two subsidy forms on remanufacturing ratio

Since this paper considers a closed loop supply chain including remanufacture, various forms of subsidies will have an impact on each member of the closed-loop supply chain, so it is necessary to study the impact of two forms of subsidy policies on the remanufactured products ratio. We use K to represent the proportion of remanufactured products in the total output when subsidies are carried out, and

$$K = \frac{d_r^*}{d_r^* + d_n^*}.$$

Figure 4.5 The relationship between optimal remanufacturing ratio and two kinds of subsidies

From figure 4.5, we can know that both subsidies will increase as the optimal re-manufacturing ratio increases. And as the remanufacturing ratio increases, the amount needed to subsidize the remanufactured goods' service level will be less than the amount needed to subsidize the service scope of the logistics provider. And the gap will widen as the remanufacturing ratio increases. This means that in order to increase the remanufacturing ratio, directly subsidizing the service level of remanufactured products will be more efficient than subsidizing the service scope of logistics providers.

5. Conclusion

In summary, from the perspective of remanufacturers, whether the government subsidizes the service or subsidizes the service scope of the logistics provider, it can improve the service level of remanufacturing and the service scope of the logistics provider. This has great stimulating significance for enterprises to produce the

408 remanufacture products and for logistics companies to expand their scope of services.
409 When comparing the two subsidy policies, the government chooses to subsidize the
410 service scope of logistics providers has greater advantages for improving the service
411 level of new products and the service scope of logistics providers. And choosing to
412 subsidize the service level of remanufactured products has higher efficiency for
413 improving the service level of remanufactured products, the optimal remanufacturing
414 rate and the demand for remanufactured products.

Appendix

1. Symbols and Their Meaning

	Symbol	Meaning
Symbol	j	$j \in \{r, n\}$, r and n represent remanufactured products and new products, respectively
	b	Remanufacturer's recovery cost
	c	Each manufacturer's product cost
	d_j	Market demand for product j , $j \in \{r, n\}$
	m	Manufacturer's service investment cost
	m_l	Logistics costs of logistics providers
	s_j	The service level of product j
	p	The selling price of the product, it is assumed that the new product will sell for the same price as the remanufactured product
	l	The service scope of logistic providers
	δ	Cost savings in remanufacturing
	τ	Degree of remanufacturing
	π	Profit function
	α_j	The market basis of product j refers to the market size when the product price is fixed and there is no service
	$\beta_s^{[19]}$	Represents the service flexibility of market demand
Subscript	r, n	r and n represent remanufactured products and new products, respectively
	s	Service
	l	Logistic providers
Superscript	M	Manufactures
	b	The optimal reaction function
	$*$	Nash Equilibrium

2. Proof of Corollary 1

$$\frac{\partial l^*}{\partial m_l} = \frac{(-\alpha_n - \alpha_r + 2\beta_p p)hm^2}{[2\beta_s h(\beta_s - \gamma_s)(2p - 2c - 2h + \delta\tau) - m_l m]^2} < 0$$

$$\frac{\partial s_n^*}{\partial m_l} = \frac{(-p + c + h)\beta_s(\alpha_n + \alpha_r - 2\beta_p p)hm}{[2\beta_s h(\beta_s - \gamma_s)(2p - 2c - 2h + \delta\tau) - m_l m]^2} < 0$$

$$\frac{\partial s_r^*}{\partial m_l} = \frac{(-p+c+h-\delta\tau)\beta_s(\alpha_n+\alpha_r-2\beta_p p)hm}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2} < 0$$

Due to $\frac{\partial l^*}{\partial m_l} < 0, \frac{\partial s_n^*}{\partial m_l} < 0, \frac{\partial s_r^*}{\partial m_l} < 0$, l^*, s_n^*, s_r^* decreases with the increase of m_l .

3. Proof of Corollary 2

$$\frac{\partial l^*}{\partial m} = \frac{-2(\alpha_n+\alpha_r-2\beta_p p)h^2\beta_s(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2},$$

$$\frac{\partial s_n^*}{\partial m} = \frac{(-p+c+h)\beta_s(\alpha_n+\alpha_r-2\beta_p p)hm_l}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2} < 0, (p > c+h)$$

$$\frac{\partial s_r^*}{\partial m} = \frac{(-p+c+h-\delta\tau)\beta_s(\alpha_n+\alpha_r-2\beta_p p)hm_l}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2} < 0, (p+\delta\tau > c+h)$$

Because $\frac{\partial s_n^*}{\partial m} < 0, \frac{\partial s_r^*}{\partial m} < 0$, s_n^*, s_r^* decrease with the increase of m . When

$\beta_s > \gamma_s, \frac{\partial l^*}{\partial m} < 0; \beta_s < \gamma_s, \frac{\partial l^*}{\partial m} > 0$, that is, when $\beta_s > \gamma_s, l^*$ decrease with the increase of m ;

When $\beta_s < \gamma_s, l^*$ increases as m increases; When $\beta_s = \gamma_s, l^* = \frac{(\alpha_n+\alpha_r-2\beta_p p)h}{m_l}$ is

not affected by the change of m .

4. Proof of Corollary 3

$$\frac{\partial l^*}{\partial \tau} = \frac{2(\alpha_n+\alpha_r-2\beta_p p)h^2 m \beta_s (\beta_s-\gamma_s) \delta}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2}, \frac{\partial s_n^*}{\partial \tau} = \frac{2(p-c-h)\beta_s^2(\alpha_n+\alpha_r-2\beta_p p)h^2(\beta_s-\gamma_s)\delta}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2},$$

$$\frac{\partial s_r^*}{\partial \tau} = \frac{-\beta_s(\alpha_n+\alpha_r-2\beta_p p)h[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h)-m_l m]}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2} > 0,$$

When $\beta_s > \gamma_s, \frac{\partial l^*}{\partial \tau} > 0, \frac{\partial s_n^*}{\partial \tau} > 0$, l^* increases as τ increases, s_n^* increase with the

increase of τ ; When $\beta_s < \gamma_s, \frac{\partial l^*}{\partial \tau} < 0, \frac{\partial s_n^*}{\partial \tau} < 0$, l^* decreases with the increase of τ ,

s_n^* decreases with the increase of τ ; When $\beta_s = \gamma_s, l^* = \frac{(\alpha_n+\alpha_r-2\beta_p p)h}{m_l}$,

$s_n^* = \frac{(p-c-h)\beta_s(\alpha_n+\alpha_r-2\beta_p p)h}{m_l m}, l^*, s_n^*$ and τ is not related. Since $\frac{\partial s_r^*}{\partial \tau} > 0$, s_r^*

increase with the increase of τ . The effect of δ on l^*, s_n^*, s_r^* is the same as that of

τ .

5. Proof of corollary 4

$$\frac{\partial l^*}{\partial c} = \frac{4(-\alpha_n-\alpha_r+2\beta_p p)h^2 m \beta_s (\beta_s-\gamma_s)}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2}, \frac{\partial s_n^*}{\partial c} = \frac{\beta_s(\alpha_n+\alpha_r-2\beta_p p)h[2\beta_s h\delta\tau(\beta_s-\gamma_s)-m_l m]}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2} < 0$$

$$\frac{\partial s_r^*}{\partial c} = \frac{-\beta_s(\alpha_n+\alpha_r-2\beta_p p)h[2\beta_s h\delta\tau(\beta_s-\gamma_s)+m_l m]}{[2\beta_s h(\beta_s-\gamma_s)(2p-2c-2h+\delta\tau)-m_l m]^2},$$

444 When $\beta_s > \gamma_s$, $\frac{\partial l^*}{\partial c} < 0$, $\frac{\partial s_r^*}{\partial c} < 0$, l^* decreases with the increase of c , s_r^* decreases with
 445 the increase of c ; When $\beta_s < \gamma_s$, $\frac{\partial l^*}{\partial c} > 0$, l^* expands with the increase of c , and
 446 $\frac{\partial s_r^*}{\partial c}$ depends on the size of $[2\beta_s h \delta \tau (\beta_s - \gamma_s) + m_l m]$. Since $\frac{\partial s_n^*}{\partial c} < 0$, s_n^* decreases with
 447 the increase of c . When $\beta_s = \gamma_s$, l^* and c is not related, $\frac{\partial s_r^*}{\partial c} = \frac{\partial s_n^*}{\partial c} < 0$, s_n^*, s_r^*
 448 decreases with the increase of c , and the decreasing trend is the same.
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