Pricing decision of remanufacturing considered product disassemblability

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Abstract: To research the effect of product disassemblability on remanufacturing pricing decisions, a CLSC (Closed-loop Supply Chain) model consisting of one OEM (Original Equipment Manufacturer) and one IO (Independent Operation) was constructed. Under centralized decision-making and decentralized decision-making with OEM leading Stackelberg game, the pricing decisions and product disassemblability strategies were studied. The impact of product disassemblability strategies on profits of members in CLSC was analyzed. At last, the coordination of revenue sharing contract with decentralized decision was investigated. Studies have shown that: It is better for OEM profit, IO profit and total profit to take coordination; H strategy is favorable for both OEM and IO. Besides, OEM and IO cooperation will to higher price for new and remanufactured products, which is bad for consumers.

Keywords: product disassemblability; pricing decision; Closed-loop Supply Chain; Stackelberg game

Introduction

China's national development and reform commission (NDRC) released data which showed household appliances have entered the scrapped peak year in China, scrapped household appliances ware more than 50 million sets in theory, the scrapped rate, average growth rate per annum of scrapped rate was 20%, and the annual scrapped volume would reach 1.6 hundred million at the final phase of the 12th Five-Year Plan (Wei Biao 2013). Large scrapped household appliances finally get into non-formal dismantling enterprises, and then be incinerated or corroded by strong acid in extensive processing method, which not only waste resources, but also seriously pollute air and water. In this regard, government has formulated relevant laws and regulations that request enterprises to recycle and recover scrapped products. Besides, enterprises found remanufacturing not only increase their environmental image, but also save the cost of manufacturing. Xerox has reduced the manufacturing cost by 40% ~ 65% through the remanufacturing process, which significantly increases the economic benefits (Xu Maozeng and Tang Fei 2013).

Therefore, researchers have focused on the issues of remanufacture pricing decisions and how to decide the level of product remanufacturability.

Product remanufacturability refers that products can be remanufacturing or not, and how to make the remanufacturing process high efficiency. Remanufacturability mains depend on product disassemblability. High level of product disassemblability can reduce the production cost of new products, at the same time, it can reduce the material and production cost of remanufactured products. But it will increase the initial investment cost of OEM. A two period model is established composed of OEM and IO (Cheng-Han Wu 2012), considering the effect of production cost and purchase intention of customers on OEM manufacturing design level decision and IO product pricing decision (Cheng-Han Wu 2013). A two period model is established composed of a manufacturer and a retailer, and analyses the influence of remanufacturing design on profit and decision-making between upstream and downstream enterprises (Hua et al. 2011).

In practice, some companies can combine forward manufacturing with reverse remanufacturing very well and achieve a win-win. It is the reason why these companies are able to succeed in remanufacturing. And that means it needs a perspective of CLSC to study the product recovery and remanufacturing.

Compared to decentralized decision-making model, the collaborative decision-making model can lead to higher profits for all members. To achieve a win-win for supply chain members, revenue sharing contract comes into being. Current research on revenue sharing contract involves many aspects. Wei-Guo Zhang et al. (2012) construct a model consist of a single manufacturer and two competing retailers, and adjusted revenue sharing contract are proposed when one or two retail's demand change. Xu Maozeng and Tang Fei(2013) aiming at the coordination problem of dual-channel CLSC, a dual-channel CLSC decision model with a manufacturer, a retailer and a third-party is established based on game theory. To make up for such efficiency loss, a profit and expense sharing contract was designed to realize the coordination of dual-channel CLSC based on the optimal result of centralized decision-making. Guangye Xu et al. (2014) consider the manufacturers and retailers have different risk preferences, construct a dual sales channel CLSC model, and propose a revenue sharing coordination mechanism. Che-Fu Hsueh (2014) constructed a two-level supply chain model, the researchers propose a sharing contract coordination considering the benefits of corporate social responsibility.

Based on the above analysis, this paper define the easy to disassemble as H strategy (means H product disassemblability strategy), and the difficult to disassemble as L strategy (means L product disassemblability strategy). In H strategy, OEM need to investment high fixed cost in the first stage, and both OEM and IO could reduce variable manufacturing or remanufacturing cost. In L strategy, OEM need to investment low fixed cost in the first stage, and both OEM and IO will increase variable manufacturing or remanufacturing cost. In the CLSC model, OEM is the game leader, IO is the game follower and affect on OEM profits, IO profit, and total profits are analyzed under different product disassembly strategies.

The model

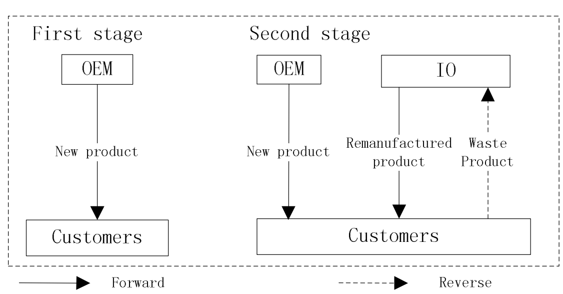

Fig. 1 Closed Loop Supply Chain Structure

This paper studies a two-stage CLSC model which consists of a single OEM and a single IO. In first stage, OEM produces new products and sells to consumers directly; in second stage, OEM continues to produce new products and sell to consumers, besides, IO recoveries waste products and remanufactures, and then sells to consumers. CLSC structure is shown in Fig. 1.

Based on model description, assumptions are on the following:

Assumption 1: New products are different with remanufactured products, and be sold in different price. In first stage, the sales price of new products is p_l. In the second stage, the sales price of new product is p_n, and the sales price of remanufactured product is p_r ($p_r < p_n$) (where, *n* represents a new product, *r* represents remanufactured product).

Assumption 2: In decentralized decision-making, OEM is the Stackelberg game leader, IO is the Stackelberg game follower. Each member makes decision according to its own benefit maximization principle.

Assumption 3: Assume there are M consumers in first stage, and $\Delta M(\Delta > 0)$ consumers in second stage (where, Δ represent the market size variation coefficient in second stage).

Assumption 4: According to Cheng-Han Wu (2012), consumers have different willingness to buy new products and remanufactured products. Assume the purchase intension to buy new products is $\theta,(\theta \sim [0,1])$, and to buy the remanufactured products is $\rho\theta(0 < \rho < 1)$,(where, ρ represent the remanufactured products purchase intention weight).

In the first stage, there are only new products, The utility value of consumers to buy new products is $U = \theta\text{-}p_l$, the demand for new products is $D_l = M(1\text{-}p_l)$.

In the second stage, the utility function of new products is $U_n = \theta - p_n$, the utility function of remanufactured products is $U_r = \rho\theta - p_r$. Assume Θ_n, Θ_r represent the sets of new products and remanufactured products for consumers. $\Theta_n = \{\theta : U_n \geq \max(U_r, 0)\}$, $\Theta_r = \{\theta : U_r \geq \max(U_n, 0)\}$. g_n, g_r represent the market share of new products and remanufactured products. $g_n = \int_{\theta \in \theta_n} f(\theta) d\theta$, $g_r = \int_{\theta \in \theta_r} f(\theta) d\theta$. Then, the demand function of new products and remanufactured products are $D_n = \Delta M g_n$, $D_r = \Delta M g_r$.

The demand for new products and products are:

New products demand: $D_n^d = \Delta M \dfrac{1 - \rho - p_n + p_r}{1 - \rho}$;

Remanufactured products demand: $D_r^d = \Delta M \dfrac{\rho p_n - p_r}{\rho(1 - \rho)}$.

Assumption 5: Product costs consist of fixed costs and unit variable cost. Fixed costs: H strategy compared to L strategy requires higher fixed costs, namely $T_L < T_H$; Unit variable cost: H strategy compared to L strategy requires lower unit variable cost both for new product and remanufactured product, namely, $c_{iL} > c_{iH}, (i = n, r)$.

Assumption 6: $\pi_k^f (f = d / c; k = m / r)$ respectively represent profit for each member in different decision-making model (where, *f=d/c*, respectively represent decentralized decision-making and centralized decision-making; *k=m/r*, represent OEM and IO).

Assumption 7: OEM and IO are risk neutral, take the maximum profits as the business goals, and information completely.

Decentralized decision-making model

OEM and IO make decision according to its own benefit maximization principle. As the leader in Stackelberg game, OEM decide the optimal price for new product p_l^{*d} in first stage, and the optimal price for new product p_n^{*d} in second stage; As the follower in Stackelberg game, IO decide the optimal price for remanufactured product p_r^{*d} in second stage. The objective functions are as follows:

$$\max \pi_m^d = (p_l - c_{nj})D_l - T_j + \delta(p_n - c_{nj})D_n^d \tag{1}$$

$$\begin{aligned} &s.t. \max \pi_r^d = \delta(p_r - c_{rj})D_r^d \\ &D_r^d \le \gamma D_1 \end{aligned} \tag{2}$$

Where, δ denote the value-discount factor over the periods, which means that a value decreases ($1-\delta$) in comparison with that in the previous period.

Using reverse solving, first, derivate p_r^d from IO profit function, and best-response function for remanufactured product $p_r^{\dagger d}$ can be obtained. Then substitute into the OEM profit function and derivate p_l^d and p_l^d, optimal prices for new products p_l^{*d} and p_n^{*d} can be obtained. Last, substitute p_l^{*d} and p_n^{*d} into the IO's best-response function to obtain the optimal prices for remanufactured products p_r^{*d}.

$$p_1^{*d} = \begin{cases} p_1^{*dU} = \dfrac{1+c_{nj}}{2}, \Delta < \Delta^d \\ p_1^{*dB} = \dfrac{1+c_{nj}}{2} + \dfrac{\delta\gamma\rho(2\Delta-\gamma\rho)(1-c_{nj})}{8\Delta - 2\delta\gamma^2\rho^2}, \Delta > \Delta^d \end{cases} \tag{3}$$

$$p_n^{*d} = \begin{cases} p_n^{*dU} = \dfrac{2(1-\rho)+(2-\rho)c_{nj}+c_{rj}}{2(2-\rho)}, \quad \Delta < \Delta^d \\ p_n^{*dB} = c_{nj} + \dfrac{(2\Delta-\gamma\rho)(1-c_{nj})}{4\Delta-\delta\gamma^2\rho^2}, \Delta > \Delta^d \end{cases} \tag{4}$$

$$p_r^{*d} = \begin{cases} p_r^{*dU} = \dfrac{2\rho(1-\rho)+\rho(2-\rho)c_{nj}+(4-\rho)c_{rj}}{4(2-\rho)}, \Delta < \Delta^d \\ p_r^{*dB} = \rho c_{nj} - \dfrac{\gamma\rho(1-\rho)(1-c_{nj})}{2\Delta} + [1+\dfrac{\delta\gamma^2\rho(1-\rho)}{2\Delta}]\dfrac{\rho(2\Delta-\gamma\rho)(1-c_{nj})}{4\Delta-\delta\gamma^2\rho^2}, \Delta > \Delta^d \end{cases} \tag{5}$$

$$\Delta^d = \frac{\gamma\rho(1-\rho)[1-c_{nj}-\delta\gamma\rho(p_n^{*dB}-c_{nj})]}{\rho p_n^{*dB} - c_{rj}} \tag{6}$$

Δ^d represent the critical point of whether remanufacturing is limited by recycling or not in decentralized decision-making model.

When $\Delta < \Delta^d$, waste products in recycling market are sufficient, IO remanufacturing is not quantitative restrictions; when $\Delta > \Delta^d$, IO remanufacturing is limited by recycling products.

Centralized decision-making model

$$\begin{aligned} &\max \pi^c = (p_l - c_{nj})D_l - T_j + \delta[(p_n - c_{nj})D_n + (p_r - c_{rj})D_r] \\ &\qquad s.t. D_r^c \le \gamma D_1 \end{aligned} \tag{7}$$

$$p_1^{*c} = \begin{cases} \dfrac{1+c_{nj}}{2}, \Delta < \Delta^c \\ 1 + \dfrac{\Delta\delta\gamma(c_{rj}-\rho c_{nj}) - \Delta(1-c_{nj})}{2\Delta + 2\delta\gamma^2\rho(1-\rho)}, \Delta > \Delta^c \end{cases} \tag{8}$$

$$p_n^{*c} = \frac{1+c_{nj}}{2} \tag{9}$$

$$p_r^{*c} = \begin{cases} \frac{\rho + c_{rj}}{2}, \Delta < \Delta^c \\ \frac{\rho}{2} + \frac{\Delta \rho c_{nj} - \gamma\rho(1-\rho)(1-c_{nj}) + \delta\gamma^2\rho(1-\rho)c_{rj}}{2\Delta + 2\delta\gamma^2\rho(1-\rho)}, \Delta > \Delta^c \end{cases} \tag{10}$$

$$\Delta^c = \frac{\gamma\rho(1-\rho)(1-c_{nj})}{\rho c_{nj} - c_{rj}} \tag{11}$$

Δ^c represent the critical point of whether remanufacturing is limited by recycling or not in centralized decision-making model.

When $\Delta < \Delta^c$, waste products in recycling market are sufficient, IO remanufacturing is not quantitative restrictions; when $\Delta > \Delta^c$, IO remanufacturing is limited by recycling products.

Numerical Analysis

In this part, an example about Lenovo computers will be analyzed. According to Cheng-Han Wu(2013), the experimental data are given: $M=20$, $\rho=0.6$, $\delta=0.9$, $\gamma=0.6$, $\Delta \in [0.5,3]$, $c_{nH}=0.4, c_{nL}=0.5$, $c_{rH}=0.2, c_{rL}=0.25$, $T_L=0.5, T_H=T_L+y, (y \in [0,2.5])$. Under the decentralized and centralized decision-making, in different product disassembly strategy, the fluctuation with the change of market size in the second stage (namely, the change of Δ)for the new product price, remanufactured product price, OEM profit, IO profit and total supply chain profit are shown in Fig.2- Fig.5.

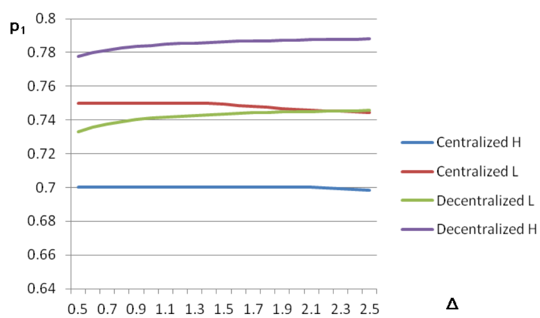

Fig. 2(a) The trend of p_1 with Δ changes

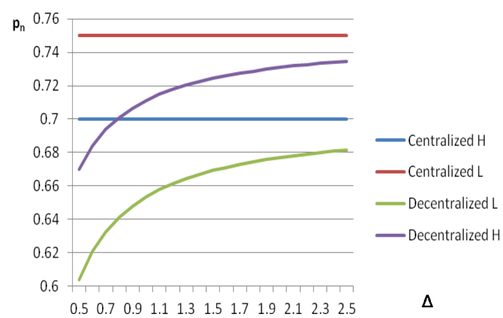

Fig. 2(b) The trend of p_n with Δ changes

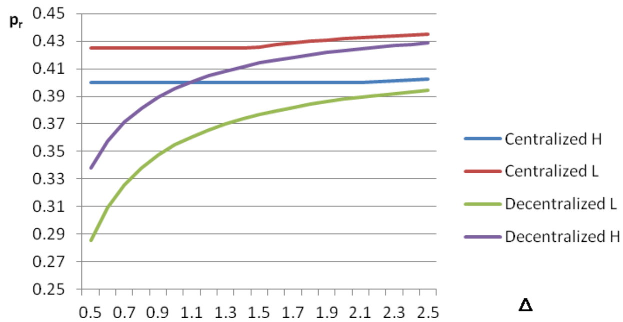

Fig. 2(c) The trend of p_r *with* Δ *changes*

Fig. 2 The trend of retail price with Δ *changes*

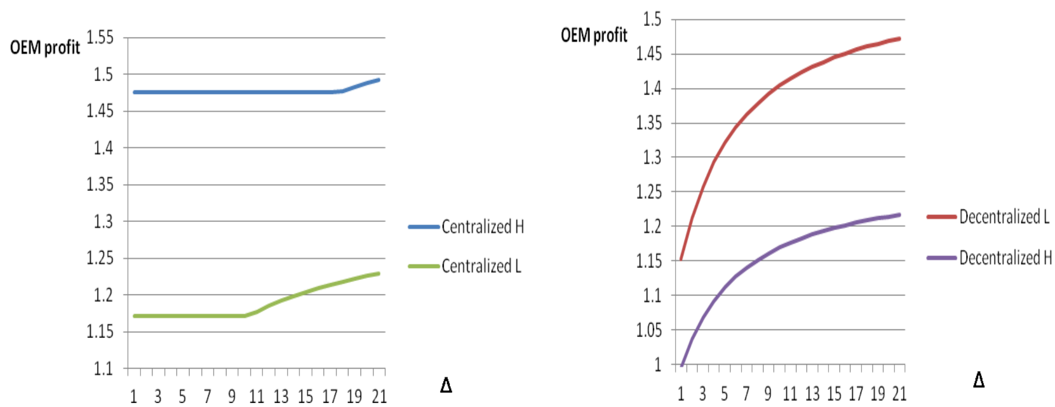

Fig. 3 The trend of OEM profit with Δ *changes*

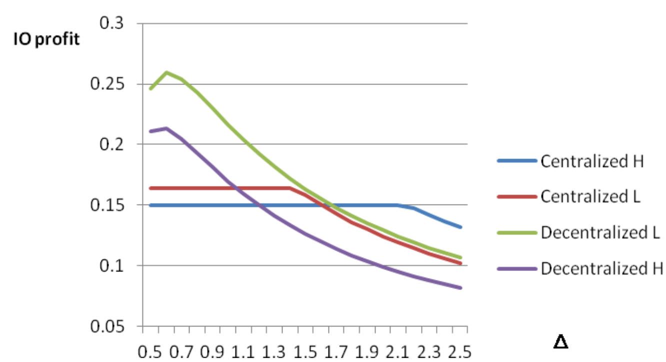

Fig. 4 The trend of IO profit with Δ *changes*

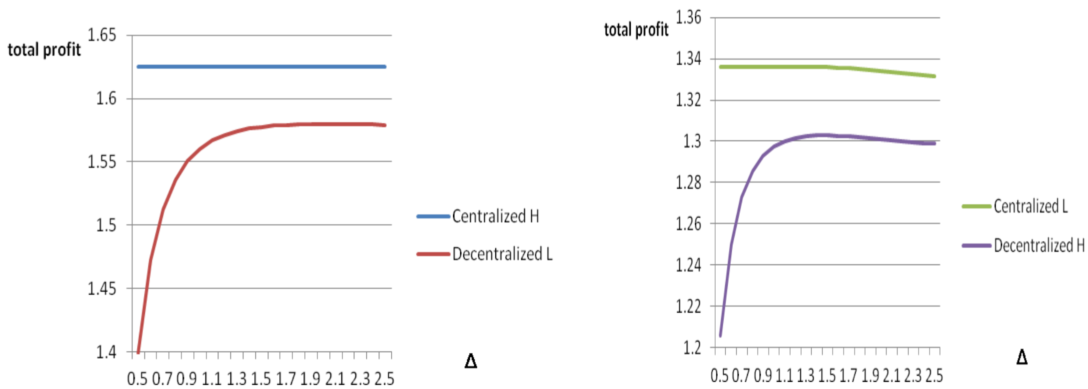

Fig. 5 The trend of total profit with Δ *changes*

Fig. 2 shows that new product price in first stage: ①Under same disassembly strategy, compared with centralized decision-making, decentralized decision-making has higher price; ②In same decision model, compared with the H strategy, L strategy has higher price. New product and remanufactured product price in second stage: ①Under same disassembly strategy, centralized decision-making has higher price; ②In same decision model, L strategy has higher price.

Fig. 3 shows that OEM profit: ① Under same disassembly strategy, centralized decision-making has higher profit; ② In same decision model, H strategy has higher profit.

Fig. 4 shows that IO profit: ① Under same disassembly strategy, when market size expands extraordinary(Δis large), centralized decision-making has higher profit; when market size reduces(Δis small), centralized decision-making has lower profit; ② Under decentralized decision-making, H strategy has higher profit.③ Under centralized decision-making, when market size expands extraordinary(Δis large), H strategy has higher profit; on the contrary, when market size reduces(Δis small), L strategy has higher profit.

Fig. 5 shows that total profit: ① Under same disassembly strategy, centralized decision-making has higher profit; ② In same decision model, H strategy has higher profit.

Conclusion 1: Compared with decentralized decision-making, the price of new product under centralized decision-making in first stage reduces. But the price of new product and remanufactured product in second stage increases. Under centralized decision-making, the OEM's profit increases, the IO's profit increase when market size expands extraordinary, the total profit increase.

The reason: under centralized decision-making, OEM and IO cooperate, thus lead to control the market price, therefore the price of the two products in the second stage increase compared to decentralized decision-making. Meanwhile, the cooperation reduce the competition, so that the total supply chain profits increase.

Conclusion 2: Taking the H strategy, OEM profit, IO profits and total profits are higher than that in L strategy.

Coordination

Revenue Sharing contract: When market size expands extraordinary (Δis large), OEM and IO come to an agreement: OEM takes H strategy, OEM and IO both increase the price of two products in the second stage.

The OEM and IO's profits are as follows:

$$\pi_m = (p_1^c - c_{nh})D_1^c - T_h + \delta(p_n^c - c_{nh})D_n^c \quad (12)$$

$$\pi_r = \delta(p_r^c - c_{rh})D_r^c \quad (13)$$

When the market is smaller (Δ is small), IO tends to decentralized decision-making model, OEM tend to centralized decision-making model, in order to improve OEM profits, OEM should propose cooperation initiatively. Assume OEM and IO come to a agreement, OEM take H strategy, OEM and IO both increase the price to reach the level of centralized decision-making. The profit distribution: Firstly, OEM and IO get the profit under decentralized decision-making; Secondly, distribute the residual profit as OEM:IO =（m：r）(m + r = 1) .

Total profit：

$$\pi = (p_1^c - c_{nh})D_1^c - T_h + \delta[(p_n^c - c_{nh})D_n^c + (p_r^c - c_{rh})D_r^c] \quad (14)$$

Profit of OEM and IO:

$$\pi_m = \frac{m}{m+r}[\pi - \delta(p_r^d - c_{rh})D_r^d] + \frac{r}{m+r}[(p_1^d - c_{nh})D_1^d - T_h + \delta(p_n^d - c_{nh})D_n^d] \quad (15)$$

$$\pi_r = \frac{r}{m+r}[\pi - [(p_1^d - c_{nh})D_1^d - T_h + \delta(p_n^d - c_{nh})D_n^d]] + \frac{m}{m+r}\delta(p_r^d - c_{rh})D_r^d \quad (16)$$

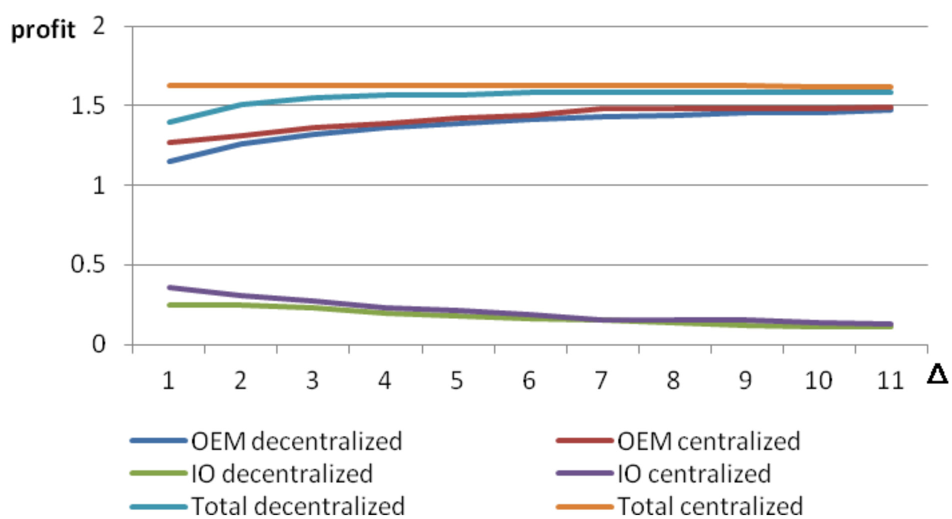

Fig. 6 Profits comparison between decentralized and centralized decision-making model

Fig. 6 shows: ①No matter the size of market is big or small, the OEM profit, IO profit and total profit are all higher under centralized decision-making model; ②OEM profit and total profit increase with the market size increase, but IO profit and total profit increase with the market size increase.

Conclusion

First, it is better for each member when OEM take H strategy, no matter how the market changes;

Second, under centralized decision-making, each member's profit and the total profit of the whole supply chain will increase compared to decentralized decision-making. It is better for both to take coordination;

Third, OEM and IO cooperation will reduce the price of new product in first stage, but will increase the price of new product and remanufactured product in second stage. It is bad for consumers.

References

Wei Biao. China promote "green recycling" of waste household appliances. http://news.xinhuanet.com/fortune/2013-03/26 /c_115160852.htm (accessed 2013).

Xu Maozeng, Tang Fei. Coordination mechanism of dual-channel closed-loop supply chain based on third-party collection. Computer Integrated Manufacturing Systems. 2013, 19(8): 2083-2089.

Cheng-Han Wu. Product-Design and Pricing Strategies with Remanufacturing. European Journal of Operational Research. 2012, 222 (2): 204–215.

Cheng-Han Wu. OEM Product Design in a Price Competition with Remanufactured Product. Omega. 2013, 41(2): 287–298.

Hua Z, Zhang X, Xu X. Product Design Strategies in a Manufacturer–Retailer Distribution Channel. Omega. 2011, 39(1): 23–32.

Wei-Guo Zhang, Junhui Fu, Hongyi Li, Weijun Xu. Coordination of supply chain with a revenue-sharing contract under demand disruptions when retailers compete. Int. J. Production Economics. 2012, 138(1): 68–75.

Guangye Xu, Bin Dan, Xumei Zhang, CanLiu. Coordinating a dual-channel supply chain with risk-averse under a two-way revenue sharing contract. Int. J. Production Economics. 2014, 147: 171-179.

Che-Fu Hsueh. Improving corporate social responsibility in a supply chain through a new revenue sharing contract. Int. J. Production Economics. 2014, 151: 214-222.

Kannan Govindan, Maria Nicoleta Popiuc. Reverse supply chain coordination by revenue sharing contract: A case for the personal computers industry. European Journal of Operational Research. 2014, 233(2): 326-336.

Cheng-Han Wu. Price and Service Competition Between New and Remanufactured Products in a Two-echelon Supply Chain. Int. J. Production Economics. 2012, 140(1): 496–507.

Serra Caner Bulmus, Stuart X. Zhu, Ruud Teunter. Competition for Cores in Remanufacturing. European Journal of Operational Research. 2014. 233 (1): 105–113.

G.D. Hatcher, W.L. Ijomah ,J.F.C. Windmill. Design for Remanufacture: a Literature Review and Future Research Needs. Journal of Cleaner Production. 2011, 19 (17-18): 2004-2014.

G.D. Hatcher, W.L. Ijomah, J.F.C. Windmil. A Network Model to Assist' Design for Remanufacture' Integration into the Design Process. Journal of Cleaner Production. 2014, 64 (1): 244-253.

Sophie Bernard. Remanufacturing. Journal of Environmental Economics and Management. 2011, 62(3): 337–351.

Martijn Thierry, Marc Salomon, Jo Van Nunen, Luk Van Wassenhove. Strategic Issues in Product Recovery. Management. California Management Review. 1995, 37 (2): 114-135.