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Closed-loop supply chain coordination based on recyclers' competition model

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SUMMARY

In a closed-loop supply chain led by manufacturing enterprises, there are often two or more recyclers that are very competitive among each other. The manufacturer may also provide many recycling contracts in order to identify recyclers' private information. This paper examines a closed-loop supply chain consisting of a manufacturer at the core of the supply chain and two competing recyclers. In order to strike a balance between its own interest and overall interest manufacturer provides two different recycling contracts: price contract and quantity contract. Two situations have been analyzed in this paper: the first in which only advantage recycler adopts quantity contract and the second in which both recyclers adopt quantity contract. A numerical simulation has been carried out according to some current data of an enterprise. In case in which the advantage recycler adopts quantity contract and the inferior recycler adopts price contract, the closed-loop supply chain has reached its equilibrium and the interests of all parties have been balanced.

***Key words**: double recycling contract, closed-loop supply chain, recyclers' competition, prices contract, quantity contract.*

1. INTRODUCTION

Thanks to its possibility to reduce resources and pollution, a considerable attention has been paid to the closed-loop supply chain by the government and academia, which both attach importance to sustainable development and low-carbon economy. The closed-loop supply chain has already been preliminary practiced by many enterprises. Through the closed-loop supply chain, a lot of value contained in EOL products can be reused in the new life cycle, which brings about reduction in energy consumption and environmental pollution caused by the EOL product. Therefore, in the light of increasing contradictions between global economic development, environmental pressure and energy supply, the importance of a closed-loop supply chain management seems even more evident due to its value in promoting the a low-carbon, environment-friendly economy. This is particularly evident in developing countries such as China. China's current practice with the closed-loop supply system is still at the initial stage and is faced with a gap between theoretical hypotheses and enterprise practice. This makes it difficult to give some theoretical support to enterprises implementing the closed-loop supply chain management system.

The instability of material supply is a major disturbance factor in remanufacturing that is a core link of the closed-loop supply chain value regeneration; therefore, coordination of recycling link would be one of the most critical bottlenecks in closed-loop supply chain coordination between the participating parties. In order to improve the quantity of recycling, remanufacturer often tends to face more recyclers which are competitive between each other. The recyclers' competition rules a clear distinction to single recovery assumes of current research. From the perspective of the core enterprise or government the question of how to design contract to influence and control recycling link in order to improve the recycling product quantity arises. This issue has become one of the important research directions of the closed-loop supply chain management practices.

2. LITERATURE REVIEW

As one of hotly debated research theories in recent years, the closed-loop supply chain coordination mainly discusses how to design contract to change the motivation of different parties in order to reduce or avoid the loss of profits. Many types of contracts have been used in the study, but the price contract coordination is the most typical contract that is divided into two subtypes: symmetric information and asymmetric information.

Price coordination is mainly concerned with the supply chain transfer price and revenue sharing between upstream and downstream that is very complex in nature. Research in this fields have been carried out by Gu et al. [1, 2] who have studied the pricing strategies by applying game theory; Debo [3] has studied remanufacturing cost from a technical and market segmentation perspective; Mukhopadhyay and Setoputro [4, 5] have discussed the optimal price and optimal return price problem from the perspective of income and cost; Ge [6] had designed a revenue sharing contract to coordinate a closed-loop supply chain under decentralized decision; Guo et al. [7] have studied two-order, closed-loop supply chain node enterprise decision and have proposed cost sharing contract for a closed-loop supply chain coordination based on the analysis of traditional revenue sharing contract and stochastic market demand.

Some scholars have discussed the decision making of various participants from the perspective of closed loop supply chain structure, such as Amaro et al. [8]. They have drawn an optimal policy under the different parties' cooperation relationship by mixed linear programming method. Qiu et al. [9] have discussed pricing decision model of two kinds of recycling mechanisms: manufacturers recycling and retailer recycling by coordination mechanisms of "two charges system", based on the assumption of market demand stochastic. Chen and Bell [10] have studied decentralized decision coordination of the product buy-back closed-loop supply chain composed of a manufacturer and a retailer. Through the un-salted product recycling prices and customers return product price, the system would coordinate supply chain system and make that the manufacturers and retailers to be win-win as well.

The above referred research is of great significance to the advancement of the closed-loop supply chain theory, but assumes that each link of the closed-loop supply chain should have one participant and does not discuss competition in case of recycling link. At the same time, the existing theoretical research method has been working on the design of some kind of contract in order to eliminate or reduce the loss of supply chain performance measured by some parameters. However, the core enterprise often offers a variety of contracts for recyclers to find recyclers' own private information in the real economy. In the case of the closed-loop supply chain practice, recyclers' competition has many important features. The two previously mentioned shortcomings are important factors that may affect the applicability of the closed-loop supply chain theory. Therefore, this paper in which double recycling contract of the closed-loop supply chain based on recyclers' competition has been studied; aims to enrich the theory of the closed-loop supply chain and provide theoretical reference for enterprise practice.

3. DOUBLE RECYCLING CONTRACT MODEL OF CLOSED-LOOP SUPPLY CHAIN BASED ON RECYCLERS' COMPETITION

Remanufactured products, as the closed-loop supply chain's final output, have different market with respect to new products in the current socio-economic environment; although in many papers these have been treated as equal to new products. In this paper, it has been assumed that the markets of new products and remanufactured products are relatively independent, which means that the consumers of new products generally do not buy the remanufactured products and the consumers of remanufactured products would not buy a new product. So, the core enterprise of the closed-loop supply chain does not consider the impact of the remanufactured products on the new products market, but only considers how the reverse supply chain profit is maximized. Remanufactured products with independent market are widespread in many industries, such as: high-end household appliances, automobiles and so on.

In this paper, the manufacturer at the same time provides two different recycling contracts: price contract and quantity contract to competitive recyclers. The double recycling contract model is more consistent with the realistic situation in the economy and is obviously different from the assumptions in many theory oriented studies.

3.1. Basic assumptions

The markets of the new products and the remanufactured products are independent of each other, so the key issue of the closed-loop supply chain have actually developed into reverse supply chain coordination problems. The basic assumptions of the model are the following:

(1) The markets of the remanufactured products and the new products are independent of each other;

(2) In the market introduction phase, all remanufactured products can be sold;

(3) The closed-loop supply chain is comprised of a core remanufacturer and two competing recyclers. When the core manufacturers make recycling price decisions, the rule is maximization of the overall profit;

(4) The core remanufacturers providing recycling prices is marked with the symbol p_{rm}, and the remanufacture costs with c. Furthermore: $p_{rm}+c < p_0$;

(5) Recycling prices of the two recyclers are p_{r1} and p_{r2}. The recycling quantity of every recycler is affected by the recycling price of both sides, and the quantity is proportional to their own price, and is inversely proportional to the competitor's price. The recycling quantity is formulated as:

$$Q_{Ri} = r + sp_{ri} - tp_{rj} \; (i=1,2; j = 3-i)$$

where s is the price-sensitive coefficient and t is the recovery competition coefficient. Consumers are more sensitive to retailers' price changes than rival price changes, so: $s - t > 0$.

Obviously, constraint condition $p_{rm} > max\{ p_{r1}, p_{r2} \}$ still exists.

Under the above assumptions, the profit of closed-loop supply chain core remanufacturer is:

$$\begin{aligned} \pi_p &= (p_o - p_{rn} - c)(Q_{R1} + Q_{R2}) = \\ &= (p_o - p_{rn} - c)[2r + (s-t)(p_{r1} + p_{r2})] \end{aligned} \tag{1}$$

(6) In addition to price contract, recyclers can also choose the quantity contract according to their own situation. Manufacturing enterprises set up a minimum recycling quantity, Q_s. When the amount of a recycler' recycling product is less than Q_s, the price of each EOL product for recyclers is $p_{rm} > max\{ p_{r1}, p_{r2} \}$ to ensure that recyclers can gain profit. When the amount of a recycler' recycling product is greater than Q_s, manufacturing enterprises should give subsidies R to the recycler which is $R > p_{rm} Q_s$ and multiply it by a coefficient to the recycling price for beyond the quantity of Q_s which is ρ and $\rho > 1$.

(7) In order to identify and encourage the advantages of suppliers, manufacturing enterprise should require that each recycler chooses his respective contract before the start of each cycle. If a recycler who has choosen the quantity contract cannot complete the requirements of the contract, he should suffer severe losses.

(8) The objective of the decision is the optimization of the whole reverse supply chain.

The profit of the two recyclers' is marked with π_1 and π_2, so the total profit of the entire reverse supply chain is:

$$\begin{aligned} \pi_{total} &= \pi_p + \pi_1 + \pi_2 = \\ &= (p_o - p_{r1} - c - c_1)(r + sp_{r1} - tp_{r2}) + \\ &+ (p_o - p_{r2} - c - c_2)(r + sp_{r2} - tp_{r1}) \end{aligned} \tag{2}$$

3.2. Quantity contract model of advantageous recycler with market independent of remanufacturing product and new product

Considering their own situation, different recyclers may have different choices. When the quantity contract and price contract are provided at the same time, the model of the quantity contract coordination has two types: advantageous recycler alone chooses the quantity contract and both recyclers choose the quantity contract.

When recycler R2 (advantageous recycler) alone chooses the quantity contract, the profit of the three parties is:

The core manufacturer:

$$\begin{aligned} \pi_p &= (p_o - p_{rn} - c)(r + sp_{r1} - tp_{r2}) + (p_o - c)Q_s - \\ &- R + (p_o - \rho p_{rn} - c)(r + sp_{r2} - tp_{r1} - Q_s) \end{aligned}$$

Recycler R1:

$$\begin{aligned} \pi_1 &= (p_{rm} - p_{r1} - c_1)Q_{R1} = \\ &= (p_{rm} - p_{r1} - c_1)(r + sp_{r1} - tp_{r2}) \end{aligned}$$

Recycler R2:

$$\begin{aligned} \pi_2 &= (\rho p_{rm} - p_{r2} - c_2)(r + sp_{r2} - tp_{r1} - Q_s) \\ &+ R - (p_{r2} + c_2)Q_s \end{aligned}$$

s.t.:

$$\begin{cases} r + sp_{r1} - tp_{r2} < Q_s \\ r + sp_{r2} - tp_{r1} > Q_s \end{cases}$$

$$p^*_{r2} = \frac{1}{2}(\rho p_{rm} - c_2) - \frac{2sr - st(p_{rm} - c_1) + tr}{2(2s^2 - t^2)}$$

$$\begin{aligned} p^*_{r1} &= \frac{t}{4s}(\rho p_{rm} - c_2) + (sp_{rm} - sc_1 - r) \cdot \\ &\cdot [\frac{1}{4s} + \frac{s}{2(2s^2 - t^2)}] - \frac{tr}{2(2s^2 - t^2)} \end{aligned}$$

Thus, the total profit of all three parties:

$$\pi_{total} = \pi_p + \pi_1 + \pi_2 = (p_o - c)Q_s - \frac{1}{4s}\{(c - p_o + \rho p_{rm})[-4Q_s s - 2c_2 s^2 + 2\rho p_{rm} s^2 +$$
$$+ c_1 st - p_{rm} st + c_2 t^2 - \rho p_{rm} t^2 + r(2s+t)]\} - \frac{1}{4(2s^2 - t^2)}\{(c - p_o + p_{rm})\cdot$$
$$\cdot[-4c_1 s^3 + 4p_{rm} s^3 + 2c_2 s^2 t - 2\rho p_{rm} s^2 t + 3c_1 st^2 - 3p_{rm} st^2 - c_2 t^3 + \rho p_{rm} t^3 +$$
$$+ r(4s^2 + 2st - t^2)]\} + \frac{1}{16s^3 - 8st^2}\{[-4Q_s s - 2c_2 s^2 + 2\rho p_{rm} s^2 + c_1 st -$$
$$- p_{rm} st + c_2 t^2 - \rho p_{rm} t^2 + r(2s+t)]\cdot[2\rho p_{rm} s^2 + c_1 st - p_{rm} st - \rho p_{rm} t^2 +$$
$$+ r(2s+t) - c_2(2s^2 - t^2)]\} + [(4c_1 s^3 - 4p_{rm} s^3 - 2c_2 s^2 t + 2\rho p_{rm} s^2 t -$$
$$- 3c_1 st^2 + 3p_{rm} st^2 + c_2 t^3 - \rho p_{rm} t^3 + r(-4s^2 - 2st + t^2)]^2 /$$
$$/[16s(-2s^2 + t^2)^2] - \frac{1}{2}Q_s[c_2 + \rho p_{rm} - \frac{(c_1 - p_{rm})st + r(2s+t)}{2s^2 - t^2}]$$

Theorem 1: When advantageous recycler chooses the quantity contract and the inferior recycler chooses the price contract, there is an optimal value of p_{rm} to the maximum total profit of the closed-loop supply chain.

Proof:

$$\frac{\partial^2 \pi_{total}}{\partial p_{rm}^2} = -16(1+\rho^2)s^6 + 4(25+7\rho^2)s^4 t^2 + 4\rho s^3 t^3 - (5+16\rho^2)s^2 t^4 - 4\rho st^5 + 3\rho^2 t^6 =$$
$$= (28s^4 t^2 + 3t^6 - 16s^{16} - 16s^2 t^4)\rho^2 + (4s^3 t^3 + 2st^5)\rho + (20s^4 t^2 - 16s^6 - 5s^2 t^4)$$

Therefore, if we want to prove that:

$$-16(1+\rho^2)s^6 + 4(25+7\rho^2)s^4 t^2 + 4\rho s^3 t^3 - (5+16\rho^2)s^2 t^4 - 2\rho st^5 - 2\rho st^5 + 3\rho^2 t^6 < 0$$

we need to prove that:

$$(28s^4 t^2 + 3t^6 - 16s^6 - 16s^2 t^4)\rho^2 + (4s^3 t^3 + 2st^5)\rho + (20s^4 t^2 - 16s^6 - 5s^2 t^4) < 0$$

and because of:

$$28s^4 t^2 + 3t^6 - 16s^6 - 16s^2 t^4 = -t^6[2(\frac{s}{t})^2 - 1]^2 \cdot [4(\frac{s}{t})^2 - 3] < 0 \quad (\frac{s}{t} > 1)$$

we obtain:

$$(4s^3 t^3 + 2st^5)^2 - 4(28s^4 t^2 + 3t^6 - 16s^6 - 16s^2 t^4)(20s^4 t^2 - 16s^6 - 5s^2 t^4) < 0$$
$$(4s^3 t^3 + 2st^5)^2 - 4(28s^4 t^2 + 3t^6 - 16s^6 - 16s^2 t^4)(20s^4 t^2 - 16s^6 - 5s^2 t^4) =$$
$$= s^2[312s^4 t^6 + 16t^{10} + 568s^8 t^2 - 896s^6 t^4 - 256s^{10} - 136s^2 t^8] < 0$$

Therefore, the theorem is proved.

Then we get that the optimal recycling price is:

$$p_{rm} = \{-2c(2s^3 - 2s^2 t - st^2 + t^3)[4(1+\rho)s^3 + 2(1+\rho)s^2 t - (1+2\rho)st^2 - \rho t^3] +$$
$$+2p_o(2s^3 - 2s^2 t - st^2 + t^3)[4(1+\rho)s^3 + 2(1+\rho)s^2 t - (1+2\rho)st^2 - \rho t^3] -$$
$$- t(-\rho(2s^2 - t^2)(4c_1 s^3 - 2c_2 s^2 t - 3c_1 st^2 + c_2 t^3) + r[8(1+\rho)s^4 + 4(2+\rho)s^3 t -$$
$$- 2(1+3\rho)s^2 t^2 - (3+2\rho)st^3 + \rho t^4] + s(-8c_2 s^4 + 10c_2 s^2 t^2 + c_1 st^3 - 3c_2 t^4)]\}/$$
$$/[16(1+\rho^2)s^6 - 4(5+7\rho^2)s^4 t^2 - 4\rho s^3 t^3 + (5+16\rho^2)s^2 t^4 + 2\rho st^5 - 3\rho^2 t^6]$$

Since the variables in the relationship of the closed-loop supply chain mode are very complex in a competitive environment, a numerical analysis has been conducted in this paper. Based on the practice of a closed-loop supply chain management of an enterprise, we assume that $r=100$, $s=15$, $t=3$, $c_1=18$, $c_2=15$, $c=30$, $p_0=98$. The calculation results show: $p^*_{rm}=56.2243$. The indicators of the closed-loop supply chain are shown in the Table 1.

Table 1. Results of the situation when recycler R2 takes the quantity contract

Indicators	Recycler R1	Recycler R2	Core manufacturer	Total
Recycling price	18.2231	24.4433	56.2243	——
Recycling quantity	300.017	411.98	711.997	711.997
Recycling profit	6000.69	1425.72+R	13872-R	21298.4
Recycling profit (R=8433.645)	6000.69	9859.365	5438.355	21298.4

Double contract, including quantity contract effects on the closed-loop supply chain, is very large and leads to a power transfer of the whole supply chain. The core manufacturer plays a control role in the closed-loop supply chain and also has the largest portion of the closed-loop supply chain profit.

(1) Because of the quantity contract, the advantageous recycler plays to the competitive advantage and highlights the market competition ability, but its earnings depend on the contract return of the core manufacturer.

(2) The difference in the recycling price between the advantageous and disadvantageous recycler is further widened. Using only the price contract, the recycling price difference is lower than the cost difference, but with the advantage recycler adopting quantity contract, the recycling price difference is increased to 2 times the cost difference. The recycling quantity of the advantage recycler is raised significantly.

(3) The decline of the total recycling quantity is not obvious. Although the quantity contract promts a transition of power in the closed-loop supply chain, the loss of the closed-loop supply chain efficiency measured by recycling quantity is not obvious. In this case, efficiency falls by only *0.84%*. So, manufacturers have good reason to encourage the advantageous recycler to accept the quantity contract.

In order to explore the relation between competitive retailers in a closed-loop supply chain, a mathematical software has been used so that the influence of some changing parameters may be analyzed. The relationship of manufacturers' recycling price, profit and recyclers' costs with quantity contract of recycler R2 is shown in Figure 1.

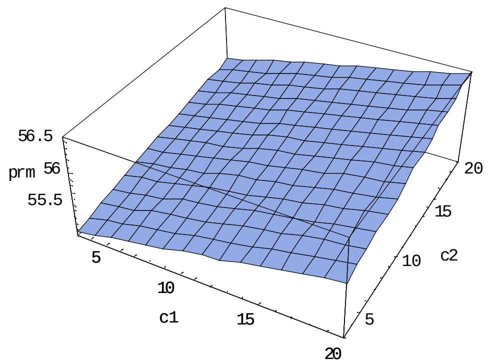

Fig. 1 Relation of manufacturers' recycling price and recyclers' costs with quantity contract of recycler R2

Only the front half of the chart is effective in Figure 1. It can be seen from the Figure 1 that the recycling price of the core enterprise is influenced by the recyclers' cost. The processing cost is higher and the recycling price of the core enterprise is consequently higher. The recycling price of a remanufacturer is so high that it seriously reduces the enthusiasm of the core enterprise to practise the closed-loop supply chain.

Only the front half part of Figure 2 is effective. The relationship between the core enterprises' recycling profit and recyclers' competition coefficient is not obvious. However, the relationship between the cost of the disadvantageous recycler R1 and recycling profit of the core enterprise is very different. The operational efficiency of the inferior recycler has great influence on the manufacturer's profits, so the manufacturer should also be paying attention to the development of inferior recyclers, give them some subsidies and help when they cooperate with advantageous recyclers. Obviously, the common development of each member of the entire ecological chain is the key to the development of the closed-loop supply.

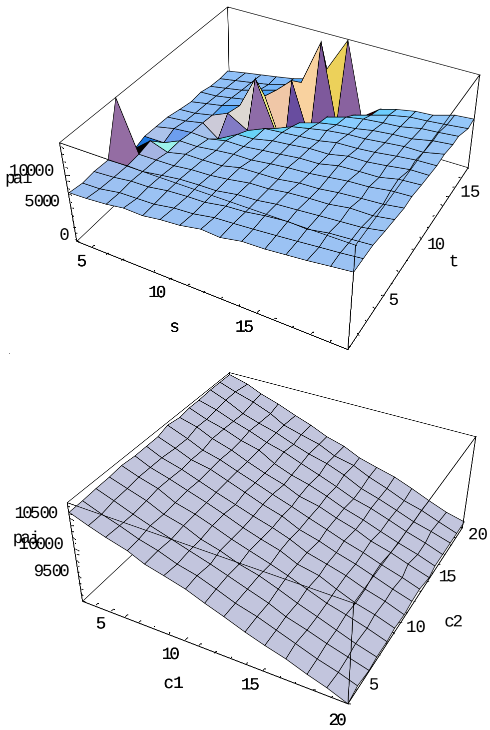

Fig. 2 Relations of manufacturers' profit and recycling price coefficient and recyclers' cost with quantity contract of recycler R2

3.3. Double quantity contract model with market independent of remanufacturing product and new product

When two recyclers adopt quantity contract, the profits of both parties can be expressed as:

$$\pi_1 = (\rho p_{rm} - p_{r1} - c_1)(r + sp_{r1} - tp_{r2} - Q_s) + R - (p_{r1} + c_1)Q_s$$

$$\pi_2 = (\rho p_{rm} - p_{r2} - c_2)(r + sp_{r2} - tp_{r1} - Q_s) + R - (p_{r2} + c_2)Q_s$$

s.t.:

$$\begin{cases} r + sp_{r1} - tp_{r2} \geq Q_s \\ r + sp_{r2} - tp_{r1} > Q_s \end{cases}$$

The optimal recycling price of two recyclers is expressed as:

$$p_{r1} = \frac{1}{2}(p_{rm} - c_1) - \frac{1}{2s}\{2r - t[\rho p_{rm} - c_2 - 2f(r(2s+t) - (p_{rm} - c_1)st)]\}$$

$$p_{r2} = \frac{1}{2}(\rho p_{rm} - c_2) - f[2rs - t(\rho p_{rm}s - sc_1 - r)]$$

The profit of the core manufacture is:

$$\pi_p = 2(p_o - c)Q_s - 2R + (p_o - \rho p_{rn} - c)[2r + (s-t)(p_{r2} + p_{r1}) - 2Q_s]$$

If used the same method as above, the total profit of a closed-loop supply chain has a maximum value. At this point, there is:

$$\begin{aligned} p_{rm} = \{ & 4p_o s^6 + 4\rho p_o s^6 + 2\rho c_1 s^5 t + 4c_2 s^5 t - 4p_o s^5 t + 2\rho p_o s^5 t + \rho c_1 s^4 t^2 - \\ & - 2p_o s^4 t^2 - 10\rho p_o s^4 t^2 - 3\rho c_1 s^3 t^3 - 2c_2 s^3 t^3 - 2\rho c_2 s^3 t^3 + 2p_o s^3 t^3 - \rho p_o s^3 t^3 - \\ & - \rho c_1 s^2 t^4 + 6\rho p_o s^2 t^4 + \rho c_1 st^5 + \rho c_2 st^5 - \rho p_o t^6 - c(2s^3 - 2s^2 t - st^2 + t^3)\cdot \\ & \cdot [2(1+\rho)s^3 + 3\rho s^2 t - \rho st^2 - \rho t^3] + r[4s^5 - 2\rho s^4 t - (2+5\rho)s^3 t^2 + 2\rho st^4]\}/ \\ & /[4(1+\rho^2)s^6 + 4\rho^2 s^5 t - \rho(4+7\rho)s^4 t^2 - 6\rho^2 s^3 t^3 + 5\rho^2 s^2 t^4 + 2\rho^2 st^5 - \rho^2 t^6] \end{aligned}$$

Using the above-mentioned data, we can calculate and obtain the closed-loop supply chain related parameters as shown in the Table 2.

Table 2. Both recyclers taking quantity contract

Indicators	Recycler R1	Recycler R2	Core manufacturer	Total
Recycling price	17.6231	25.3202	56.6829	——
Recycling quantity	288.386	426.934	715.32	715.32
Recycling profit	R-860.263	1622.82+R	20391.9-2R	21154.457
Recycling profit (R=8502.435)	7642.172	10125.255	3387.03	21154.457

When both recyclers adopt quantity contract, the effect of power transfer is more significant in the closed-loop supply chain, but the core manufacturer's profit declines.

(1) When both recyclers adopt quantity contract, the price gap between the recyclers is widened, and the strength of the advantageous recycler is enhanced. This istuation is a powerful tool for the core manufacturer who then identifies the advantageous recycler and establishes a close partnership with him.

(2) The core manufacturer's profit and the total profit of the closed-loop supply chain both fall to the lowest value in the several cases. The situation is the most favorable for the advantageous recycler which acquires more than half the total profit of the whole reverse supply chain. That is to say, the amount of advantageous recycler's profit rising significantly represents the decline in the efficiency of the whole reverse supply chain, although the rate of decline is not high, it is only 1.6%. Obviously, providing both recyclers with a quantity contract is not favourable for the core manufacturer.

(3) The recycling quantity does not change significantly and rises slightly in comparison with the situation in which only advantageous recycler adopts the quantity contract. Effect of the quantity contract for the efficiency of the closed-loop supply chain measured by recycling quantity is very small, so the government and the society should not have any preferences to the adoption of the double quantity contract.

In the case of the information symmetry, different contract can cause a dramatic shift of power in the closed-loop supply chain. Therefore, when a manufacturer is the core enterprise of a closed-loop supply chain in order to maximize their own interests and in order not to reduce the recycling quantity too much, the optimal choice is to make the advantageous recycler choose a quantity contract, and disadvantageous a price contract.

4. CONCLUSIONS

When the core manufacturer is in a leading position, it can provide two kinds of contracts for recyclers at the same time: price contract and quantity contract. The matrix game of two recyclers is shown in Figure 3.

		Recycler R2	
		Price contract	Quantity contract
Recycler R1	Price contract	(8014.66 , 9189.57)	(6000.69 , 1425.72+R) (6000.69 , 9859.365)
	Quantity contract	——	(R-860.263 , 1622.82+R) (7642.172 , 10125.255)

Fig. 3 Two recyclers matrix countermeasure with manufacturers provide double contract

Obviously, choosing the quantity contract is the best choice for both recyclers. However, in such a situation the equilibrium of the lower right corner would be impossible because the core enterprise cannot disregard their own interests when the manufacturer occupies the advantageous position in a close-loop supple chain. The core enterprise will prompt that the equilibrium moves to the right so that the upper right corner becomes the most favorable and convenient to prospective recyclers.

As the profit efficiency loss of double quantity contracts of closed-loop supply chain, the balance of the lower right corner cannot be realized automatically and also is not necessary (the cost of control supply chain including double loss of recycling profit and quantity is too high). Obviously, the upper right corner is the most optimal choice for manufacturing enterprise when it has the initiative. The profit equilibrium value of three parties' game is:

$$\vec{\chi}(M, R1, R2) = (5438.355,\ 6000.69,\ 9859.365)^T$$

Although the manufacturer did not gain maximum profit by holding core power, this equilibrium is the maximum value of its profit and, at the same time, effectively encourages the development of recycling process of a closed-loop supply chain. That can be regarded as a powerful measure in promotion of the development of the closed-loop supply chain quickly for the current situation in China where manufacturing enterprise strength, main profit from forward supply chain and the recycling link are the bottleneck of the closed-loop supply chain. In addition, the government could also contribute by giving some subsidies or making a policy for the core manufactures who had taken relevant countermeasures in order to promote the development of recycling process.

5. ACKNOWLEDGMENT

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KOORDINACIJA ZATVORENOG OPSKRBNOG LANCA TEMELJENA NA MODELU NADMETANJA PRUŽATELJA USLUGE RECIKLIRANJA

SAŽETAK

Zatvoreni opskrbni lanac obično se sastoji od proizvođača kao voditelja lanca te dvaju ili više pružatelja usluga recikliranja među kojima obično vlada oštra konkurencija. Stoga, proizvođač pruža više ugovora za reciklažu kako bi identificirao privatne informacije pružatelja usluge recikliranja. U ovome se radu proučava zatvoreni opskrbni lanac koji se sastoji od proizvođača u središtu sustava te dvojice konkurentskih pružatelja usluge recikliranja. Kako bi postigao ravnotežu između vlastitih i općenitih interesa, proizvođač nudi dva različita ugovora za reciklažu: ugovor o cijeni i ugovor o količini. Nadalje, u ovome se radu analiziraju dvije situacije: jedna u kojoj jedino pružatelj usluga s konkurentskom prednošću potpisuje ugovor o količini i druga u kojoj oba konkurenta za reciklažu potpisuju ugovor o količini. Također, provedena je i numerička simulacija na temelju podataka jednog aktualnog poduzetničkog pothvata. U slučaju kada konkurent s prednošću preuzima ugovor o količini, a slabiji konkurent potpisuje ugovor o cijeni, postiže se stanje ravnoteže ekonomskih snaga i djelovanja te su interesi svih sudionika u procesu zadovoljeni.

Ključne riječi: *dvostruki ugovor za reciklažu, zatvoreni opskrbni lanac, nadmetanje pružatelja usluga recikliranja, ugovor o cijeni, ugovor o količini.*