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Reverse Supply Chain Coordination for E-waste Recycling Based-on Option Contract

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**Abstract:** In reverse supply chain of e-waste, collectors (collecting e-waste from all kinds of resources) and processors (disassembling and disposing e-waste) play key roles and have connections based on interests. We present a Stackelberg leader(collector)-follower(processor) dynamic game model with profit maximization purpose. When the supply and demand are relatively clear, major risk for the processor comes from the uncertainty of price, if the price at which recycled raw material is sold to producer is not enough to compensate for buying, processing and possible land filling e-waste, the processor is unable to make profit. So we propose an option contract in which the collector will buy raw material from the processor at a fixed price in the future. This option will guarantee the processor profitable and increase her effort to order more e-waste from the collector. We show that this contract is Pareto improving in the majority of cases. Our results also indicate that the profit improvement to both parties, and the supply chain is substantial.

**Keywords:** reverse supply chain; e-waste recycling; coordination; option contract

## **1. Introduction**

The production of electric and electronic equipment (EEE) is one of the fastest growing businesses in the world. In the meantime, both technological innovation and market expansion of EEE are accelerating the replacement of outdated EEE, leading to a significant increase in waste EEE (WEEE or e-waste) that induces a new environmental challenge (Wenzhi He et al. 2006). E-waste, is an emerging problem as well as a business opportunity of increasing significance, given the volumes of e-waste being generated and the content of both toxic and valuable materials in them. The fraction including iron, copper, aluminum, gold and other metals in e-waste is over 60%, while pollutants comprise 2.70% (Rolf Widmer et al. 2005). Therefore, recycling of e-waste is an important subject not only from the point of waste treatment but also from the recovery aspect of valuable materials (Jirang Cui et al. 2003). However the process of take-back and disposal of e-waste is very complex, which involves various kinds of products, many people and enterprises, extensive areas, and long time span (sometimes is even over ten years), it is a huge and complicated system engineering. Extended Producer Responsibility (EPR), which originated from Europe in the 1990s, represents the transformation trend of the management model of disused products in the world. It has been defined by Lindhqvist (2000) as “. . . a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the producer of the product to various parts of the products lifecycle, and especially to the take-back, recovery, and final disposal of the product” (Lindhqvist, 2000 cited in Van Rossem et al., 2006). Under the constraint of EPR, producers can embody their extended

responsibility through direct or indirect way of take-back. In fact, most medium and small producers can't afford to build up the reverse logistics system, and they lack the professional knowledge, techniques, as well as experience to engage in the reverse logistics. Thus, the professional operation of the third party contract providers for reverse logistics seems much more advantageous. In order to concentrate on the core business, big producers also need the third party to share part or all of their reverse logistics activities. As a result, like the third party of forward logistics, the third party of reverse logistics is the definite trend of reverse logistics. In this reverse logistics, e-waste would be collected from all kinds of resources by a third party contract provider (called collector), and then it would be delivered to a processor that can recycle valuable parts from e-waste and dispose rest hazardous components environmentally. And the producer may buy those recycled valuable parts as raw material from the processor, therefore a closed-loop supply chain would be formed. Obviously collectors and processors play key roles and have connections based on interests in this reverse supply chain of e-waste. This paper focuses on their roles from game theory perspective. Collectors reclaim e-waste from sources such as consumers, and then sell e-waste to processors. For collectors, their profits are generated from the price difference of buying and selling. In order to maximize profit, collectors need to minimize inventory cost when their bought quantity is larger than the demand from processors. Meanwhile not satisfying processors' demand is also unwanted. Although processors also have the problem to minimize inventory cost as collectors do, they prefer that collectors keep adequate inventory such that processors can change their orders according to producers' demands.

This relationship between collectors and processors and their goals of maximizing profits gives us opportunity to study their behaviors, and therefore shed light to the research of reverse logistics of e-wastes. The rest of the paper is organized as follows. In Section 2, we review the relevant literature and describe some basic assumptions. Section 3 presents a dynamic Stackelberg game model and its fuzzy search optimization algorithm, illustrates the importance of coordination between collectors and processors based on simulations. Section 4 introduces an option contract coordination model to improve the entire e-waste reverse supply chain. Section 5 concludes the paper.

## **2. Literature Review and Assumptions**

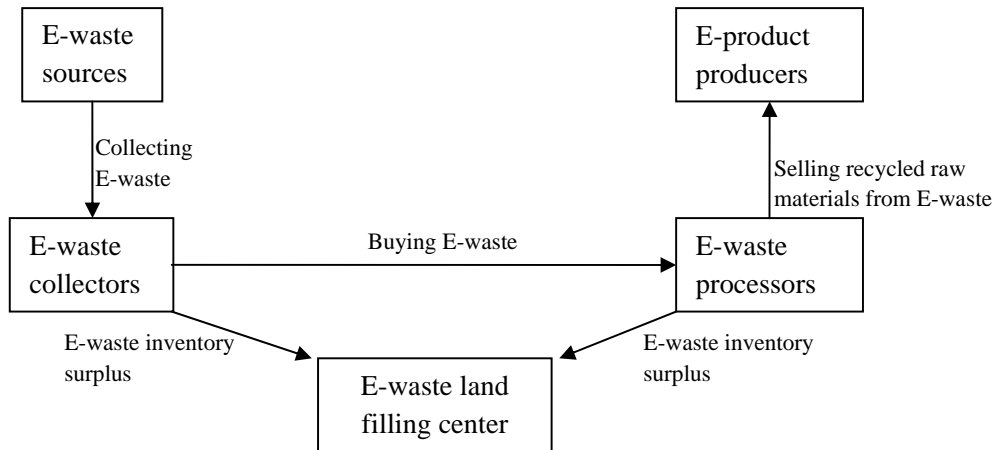
### **2.1 Literature Review**

Game theory models helped to understand the strategic implications of product recovery. Contracting is of great importance in closed-loop supply chains because they typically have an increased number of actors (e.g., third-party contract providers for reverse logistics, product disposition, remanufacturing, and remarketing).V. Daniel R. Guide Jr. et al.(2009) named coordinating as Phase 3 research of the closed-loop supply chain. Examining the entire process exposed huge information asymmetries and incentive misalignment issues in the reverse supply chain, hence the research interest in coordination issues (for an example, see Yadav et al. 2003). Savaskan et al. (2004) analyzed the problem of who (retailer, third-party collector or producer) should collect the returned products under monopoly and competitive situations. If a firm does not properly organize its access to used products, it cannot benefit from remanufacturing. Therefore, the producer has an interest in aligning incentives for this purpose. Ferguson

et al. (2006) took the collection issue a step further by acknowledging that return rates can be influenced, extending the system to the behavior of the reseller, which can be affected by the right incentives. This introduces marketing elements to the field and illustrates the increased scope of closed-loop supply chain research. The outputs of Phase 3 provided greater understanding of downstream channel design issues (Majumder and Groenevelt 2001, Savaskan et al. 2004), upstream durability decisions (Debo et al. 2005), the role of trade-ins (Ray et al. 2005), the interactions between new and remanufactured products (Ferrer and Swaminathan 2006), and reduced reseller return rates (Ferguson et al. 2006). This Phase 3 established closed-loop supply chains as a full-fledged supply chain subfield using a business economics approach to product returns (V. Daniel R. Guide Jr. et al. 2009). However, we find that there are little papers focusing on coordination between collectors and processors. In fact, their behaviors and relationship will affect greatly the e-waste return rates and the disposal of hazardous components environmentally.

## **2.2 Assumptions**

As shown in Figure 1, e-waste collectors and processors earn profit via reclaiming and processing e-waste respectively. Because of incomplete sharing of information, both of them face inventory risks. According to characteristics of reverse logistics, inventory surplus (that is, extra e-waste) is sent to independent e-waste landfills, with cost covered by collectors or processors, depending on where the inventory surplus is from. The Stackelberg game model in this paper consists of one collector and one processor. E-waste supply from consumers and demand from producers are taken as following certain distributions. Nevertheless, prices are affected by both demand and supply.



**Figure 1 Flow Chart of E-Waste Reverse Logistics**

The following assumptions are imposed:

- 1) Supply information from consumer market follows certain distribution, so does demand information from producer market. All these information is available to both collectors and processors, and information is used when they decide order quantities.
- 2) Based on economic man assumption, all players in the reverse supply chain make decisions independently and in order to maximize their interests. They are also risk neutral. Correspondingly, the reverse supply chain is decentralized.
- 3) This paper focuses on researching game theory between collectors and processors. Without loss of generality, we simplify by only studying one type of e-waste and one type of raw material that the e-waste is processed to. A fixed ratio exists between the e-waste and the raw material.
- 4) Supply and demand determine prices at which e-waste is bought at, is sold at.

Decision makings of collector and processor can be described as following: Firstly, collector decides its order of e-waste based on consumers' supply information, then processor decides its order based on collector's supply and producer's demand, in the hope of maximizing its own profit. In the second round, order of processor is acknowledged by collector, who will adjust its order from consumers to maximize its profit. In the next round, this change will also lead processor altering its demand and supply. Finally, equilibrium will be achieved as the optimal e-waste order strategy. These rounds of game are called Stackelberg game. Collector leads the game while processor follows. Collector is in a better position because it has the advantage of observing processor's decision and altering its own according to it. However, collector is not completely controlling processor's decision. This is a typical decentralized supply chain. Multi-level programming model is a good choice for Stackelberg game. In this particular case, two level programming is applied, i.e. one decision maker corresponds to one goal at the upper level, and to one goal at the lower level. Equilibrium is achieved dynamically.

### **3. Dynamic Stackelberg game model of e-waste reverse logistics**

Following are variables in an e-waste reverse logistics model involving consumer, collector, processor, and producer:

- 1)  $S$  is the total quantity of e-waste in the consumer market, it follows  $N(S^0, \sigma_1)$ .
- 2)  $D$  is demand of raw material from producer, it follows  $N(D^0, \sigma_2)$ .
- 3)  $q_r, q_p$  are the ordered quantities by collector from consumer, and by processor from collector respectively. They are also the decision variables in this model.

- 4)  $\rho_r = \rho_r(S, q_r)$  is the price at which collector reclaims e-waste from consumer.
- 5)  $\rho_p = \rho_p(a \cdot q_r, b \cdot q_p)$  is the price at which processor buys e-waste from collector.  $a, b$  are purchasing tendencies of collector and processor respectively (both of them follow the economic man assumption). Larger the value is, the stronger the purchasing tendency is, and therefore  $\rho_p$  is affected. It is also assumed that  $a, b$  are affected by coordination scheme.
- 6)  $\rho_D = \rho_D(\alpha q_p, D)$  is the price at which producer buys raw material at, where  $\alpha$  is the ratio at which e-waste is converted to raw material.
- 7)  $L_r(q_r, q_p)$  is the cost to landfill for collector. If  $q_p < q_r$ , this cost occurs. Similarly,  $L_p(q_p, \frac{D}{\alpha})$  is the cost to landfill for processor.
- 8)  $C_r(q_r)$  is the cost occurred to collector after e-waste is bought from consumer, such as stock, classification, categorization, and distribution.
- 9)  $C_p[\min(q_p, \frac{D}{\alpha})]$  is the cost for processor to process e-waste.

Collector profit is:  $\Pi_r(q_r) = \rho_p(q_r, q_p) \cdot q_p - \rho_r(S, q_r) \cdot q_r - L_r(q_r, q_p) - C_r(q_r)$

Processor profit is:  $\Pi_p(q_p) = \rho_D(\alpha q_p, D) \cdot \min(\alpha q_p, D) - \rho_p(q_r, q_p) \cdot q_p - L_p(q_p, \frac{D}{\alpha}) - C_p[\min(q_p, \frac{D}{\alpha})]$

A two-level programming model is:

$$\begin{aligned}
\max \quad & \Pi_r(q_r) = \rho_p(a \cdot q_r, b \cdot q_p) \square q_p - \rho_r(S, q_r) \square q_r - L_r(q_r, q_p) - C_r(q_r) \\
\max \quad & \Pi_p(q_p) = \rho_D(\alpha q_p, D) \square \min(\alpha q_p, D) - \rho_p(a \cdot q_r, b \cdot q_p) \square q_p - L_p(q_p, \frac{D}{\alpha}) \\
& \quad - C_r[\min(q_p, \frac{D}{\alpha})] \\
\text{st:} \quad & S \geq q_r \\
& q_r \geq q_p \\
& q_r, q_p > 0
\end{aligned} \tag{1}$$

This model is a Stackelberg leader-follower dynamic game model, where collector, as the leader, decides its own order quantity  $q_r$ , and the processor, as the follower, optimizes its order  $q_p$  according to the leader's behavior.

Even the simplest two-level linear programming is a NP problem, there does not exist polynomial-time algorithm solution. Popular alternatives include extreme point algorithm, branch-bound algorithm, descent algorithm and intelligent optimization algorithm, where the first two are mainly applied for two-level linear programming, and descent algorithm generally requires gradient information and thus is difficult to solve. Heuristic intelligent optimization algorithm has been an active research field recently, it is especially effective for large-scale problem solving. This paper uses fuzzy travelling search optimization algorithm to solve the model stated above.

### 3.1 Fuzzy search optimization algorithm

Fuzzy search algorithm has the property of travelling, and is able to search all points in an interval, thus converges to global optimal solution with probability 1. It does not require the form of lower level feedback function, nor does it have restriction on objective function; either concave or convex, either discrete or continuous variables. All it requires is the support of the variable. Chaos search algorithm in two-level

programming takes the upper level decision variable as chaos variable, and takes it to lower level, which uses traditional single level algorithm to solve the problem. In this paper, SQP method is used in SAS software. The basic steps can be described as follows:

- ① Generate initial fuzzy variable, use formula  $x_{n+1} = 4x_n(1-x_n)$  to give  $m$  the initial value  $x_0$ , where  $x_0$  cannot be 0, 0.25, 0.5, 0.75, 1, and generate  $x_n$ , the chaos variable on interval  $[0,1]$ .
- ② Take  $q_r$  ( $q_r \in [0, S]$ ), the upper level variable in two level programming, as the fuzzy variable  $q_r^n$  according to the function  $q_r^n = c + d x_n$ , where  $c, d$  are constants,  $c = -\varepsilon_1, d = S + \varepsilon_2$ ,  $\varepsilon_1$  and  $\varepsilon_2$  are arbitrarily small positive,  $\varepsilon_1 < \varepsilon_2$ .

This method enables each value of  $q_r$  be traversed.

- ③ Let  $k = 0$ , and iterative steps as  $N$ , upper level objective function is set as a very small value  $F^*$ .
- ④ The upper level coefficient  $q_r^k$  in ② is brought to lower level programming, PROC NLP in SAS is used to solve the lower level programming. Since the problem of  $\min(\alpha q_p, D)$  exists in the lower level programming model, two cases are considered:  $\alpha q_p > D$  and  $\alpha q_p < D$ . Correspondingly there are two optimal solutions  $q_p^{k,1}$  and  $q_p^{k,2}$ . They are brought back into upper level programming, and two optimal solutions  $q_r^{k,1}$ ,  $q_r^{k,2}$  as well as  $F_k^1$ ,  $F_k^2$  are derived.
- ⑤ If  $q_p^{k,1} < q_r^{k,1} < S$ ,  $\alpha q_p^{k,1} > D$  and  $q_p^{k,2} < q_r^{k,2} < S, \alpha q_p^{k,2} < D$ , i.e. restrictions are

satisfied in both cases, then values of  $F_k^1$  and  $F_k^2$  can be compared, the larger one  $F_k^i$  is kept. If  $F_k^i > F^*$ , then let  $F^* = F_k^i$ ,  $q_r^* = q_r^{k,i}$ ,  $q_p^* = q_p^{k,i}$ , and go to step ⑥. If restrictions are not satisfied in both cases, let  $k = k + 1$ , and repeat step ④. If restrictions are satisfied only in the case of  $F_k^i$ , then let  $F^* = F_k^i$ ,  $q_r^* = q_r^{k,i}$ ,  $q_p^* = q_p^{k,i}$ , and go to step ⑥.

⑥ When restrictions are satisfied, stop at  $k=N$ , optimal solutions  $q_r^*$ ,  $q_p^*$  and optimal value  $F^*$  are exported, otherwise let  $k = k + 1$  and repeat step ④.

### 3.2 Centralized supply chain model

An equilibrium solution can be derived for Stackelberg dynamic game model as described above. In the equilibrium, neither the collector nor the processor has the motive to change their strategy unless the other part does so. However, the equilibrium is not necessarily Pareto optimal for the whole system. If trust and cooperation between the collector and processor exist, both of them will be benefitted. Obviously, the cooperation only is possible when it brings at least as much profit as when there is no cooperation.

Supply chain optimization model, also known as Centralized supply chain model is as follows:

$$\begin{aligned}
\max \quad & \Pi_p(q_p) = \rho_D(\alpha q_p, D) \square \min(\alpha q_p, D) - \rho_r(S, q_r) \square q_r - L_r(q_r, q_p) - C_r(q_r) \\
& - L_p(q_p, \frac{D}{\alpha}) - C_p[\min(q_p, \frac{D}{\alpha})] \\
\text{st:} \quad & S \geq q_r \\
& q_r \geq q_p \\
& q_r, q_p > 0
\end{aligned} \tag{2}$$

The optimal solution derived from centralized supply chain model leads to win-win for both collector and processor. However, this situation is not stable; based on economic

man assumption, processor in reverse supply chain will not choose to cooperate with collector, in order to maximize its profit, processor can have higher profit than the profit it gains in Stackelberg game. For collector, it does not want to lose its leader role in the game. If there is not a scheme to coordinate, collector will be harmed, and so is the entire reverse logistics system, both from economic and social perspectives, the following shows this.

### 3.3 Example test and analysis

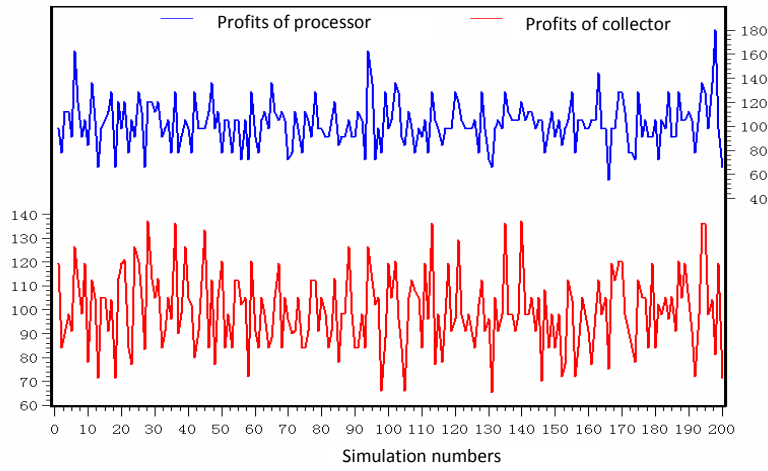
In order to understand the model better and to verify conclusions above, an example in which one collector and one processor play is given, it is a one-to-one two level programming model. To simplify the case, dimensions are not taken into consideration.

Let  $S$ ,  $D$  both identically follow normal distribution  $N(18,2)$ , price function is  $\rho_r = 15 - S + q_r$ ,  $\rho_p = 20 - q_r - q_p$  (there is no coordination scheme,  $a = b = 1$ , all players in the reverse supply chain are in the purchasing neutral position),  $\rho_D = 25 - q_p + D$  ( $\alpha = 1$  is set for convenience, i.e. one unit of e-waste can be converted into one unit of raw material),  $L_r(q_r, q_p) = q_r - q_p$ , i.e. the cost of land filling one unit of e-waste is 1,  $L_p(q_p, D) = \max(q_p - D, 0)$ , since it is not determined which one of  $q_p, D$  is greater,  $C_r(q_r) = q_r$ , i.e. cost for collector to store and to distribute one unit of e-waste is 1,  $C_r[\min(q_p, D)] = \min(q_p, D)$ , i.e. it costs the processor 1 to process one unit of e-waste into raw material.

This example model can be written as:

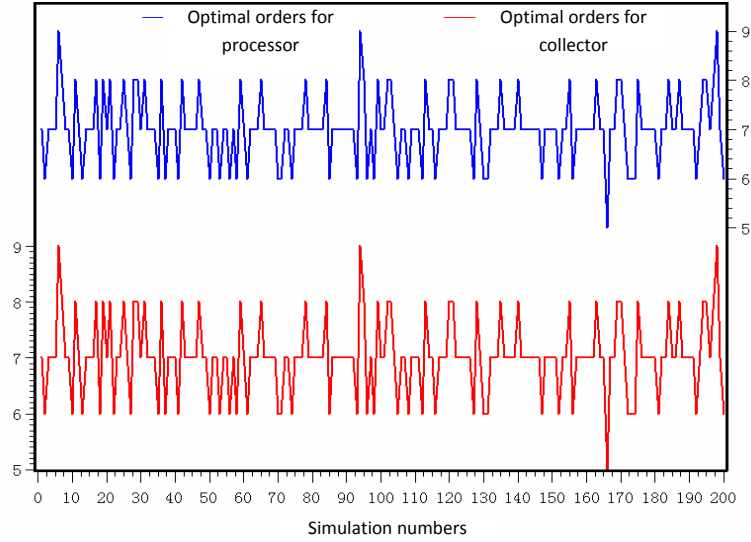
$$\begin{aligned}
\max \quad & \Pi_r(q_r) = (20 - q_r + q_p)q_p - (15 - S + q_r)q_r - (q_r - q_p) - q_r \\
\max \quad & \Pi_p(q_p) = (25 - q_p + D)\min(q_p, D) - (20 - q_r + q_p)q_p - \max(q_p - D, 0) \\
& \quad - \min(q_p, D) \\
\text{st:} \quad & S \geq q_r \\
& q_r \geq q_p \\
& q_r, q_p > 0
\end{aligned} \tag{3}$$

Using fuzzy search optimization algorithm, in SAS set  $S, D$  as random following  $N(18, 2)$  distribution, 200 simulations give results shown in Figure 2 and 3:



**Figure 2: Optimized profits for collector and processor**

Based on simulations above, Stackelberg leader-follower dynamic game has an equilibrium solution, the average optimal profit for collector is 99.57, and that for processor is 102.37. Both of them keep their orders at approximately 7, the larger the order is, the more they can benefit.



**Figure 3: Optimized orders for collector and processor**

In order to compare with centralized supply chain and decentralized coordination models studied later, we consider the case in which supply and demand are both at mean levels, i.e.  $s = D = 18$ , which enable us to compare under certain demand and supply levels. Following results can be calculated:

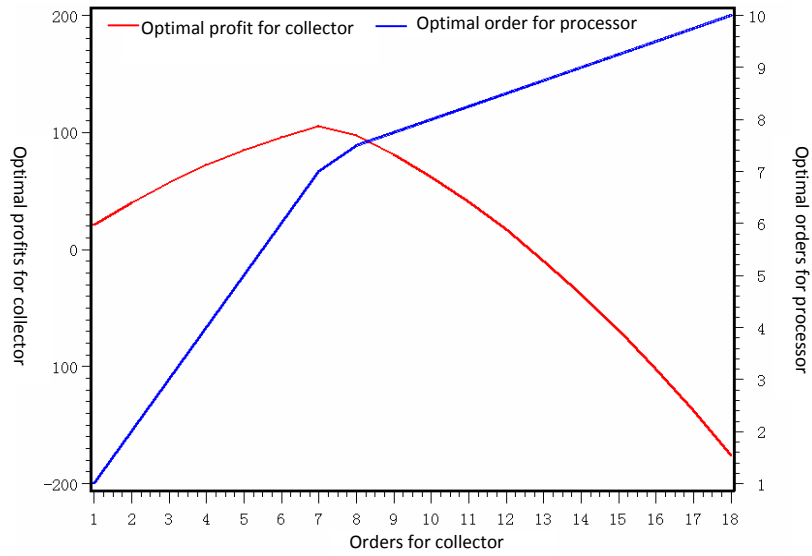
$$q_r = 7, q_p = 7; \rho_r = 4, \rho_p = 20$$

And profits for collector and processor are, respectively,

$$\Pi_r(q_r) = 105, \Pi_p(q_p) = 105$$

The total profit for the supply chain is  $\Pi = 210$ . Figure 4 depicts the decision makings for collector and processor in this case.

From Figure 4,  $q_r$  is chosen to be 7 by collector to maximize its profit, and correspondingly processor chooses optimal order  $q_p = 7$ .



**Figure 4: Decision makings for collector and processor**

This solution is the optimal one for two-level programming model, each objective achieves optimization. Under the equilibrium price, no party has the motivation to change its own price, thus a stable situation is achieved. However, if information is shared between the two parties, and if cooperation is possible (the reverse logistics model now is centralized supply chain model), then profits for both parties may increase. According to centralized supply chain model, optimal solution is derived as follows:

$$q_r = 11, q_p = 11, \rho_r = 8, \rho_p = 20$$

The profits for collector and processor are, respectively,  $\Pi_r^1(q_r) = 121$ ,  $\Pi_p^1(q_p) = 121$ . Total profit for the whole supply chain is  $\Pi^1 = 242$ .

Since  $\Pi^1 > \Pi$ , and both collector and processor are bettered off in the second situation, it is safe to say that centralized supply chain is preferred to distributed supply chain from effectiveness point of view. But risk exists for players in reverse supply chain, especially for collector, in the centralized supply chain. It can be shown that, after upper level decision maker decides its order to be  $q_r = 11$ , lower level decision maker will make its

optimal order to be  $q_p=8$  according to economic man assumption. In this case, it can be calculated that processor profit is  $\Pi_p^2(q_p)=136.13 > \Pi_p^1(q_p)$ , and collector profit is  $\Pi_r^2(q_r)=40.56 < \Pi_r^1(q_r)$ . Therefore if collector decides its  $q_r=11$ , the processor would choose not to cooperate, which harms not only the collector but also the entire reverse supply chain.

In this analysis, it can be found out that, when processor is economic man and this is known to collector, collector would choose not to cooperate with processor since it brings more profit and collector possesses more information than processor. In order to maximize the profit for the whole reverse supply chain, and to achieve win-win outcome, some coordination scheme is needed to motivate processor to cooperate with collector, and to share information. The detailed three cases are listed in Table 1.

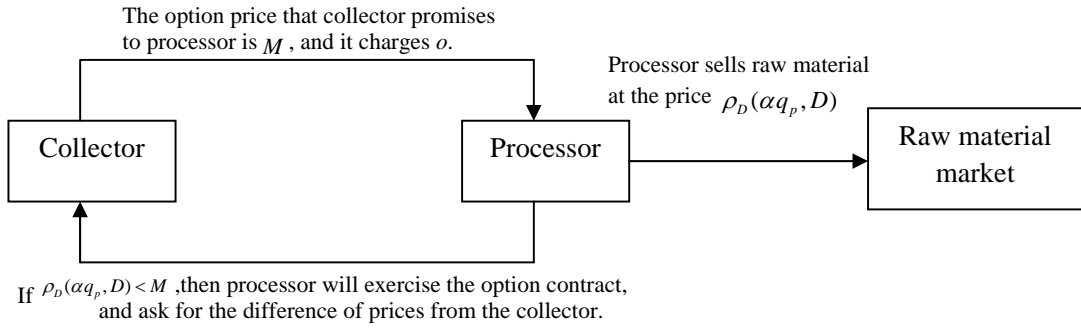
**Table 1: Cooperation strategies and results**

	<i>Stackelberg</i>		<i>Centralized supply chain</i>		<i>Processor not cooperating with collector</i>	
	Order	Profit	Order	Profit	Order	Profit
Collector	7	105	11	121	11	40.56
Processor	7	105	11	121	8	136.13
Supply Chain		210		242		176.69

#### **4. Contract model based on option coordination**

When the supply and demand are relatively clear, major risk for e-waste processor comes from the uncertainty of price, if the price at which raw material is sold to producer is not enough to make up for buying, processing and possible land filling e-

waste, processor is unable to make profit. As the leader in the model, the collector can sign option contract with processor, agreeing to buy raw material from processor at a fixed price  $M$  at an agreed time point in the future. This contract will guarantee processor profitable. Meanwhile, collector can charge  $o$  for the contract from processor to secure its own interest. This option is similar to put option in finance. The detailed operation is shown in Figure 5.



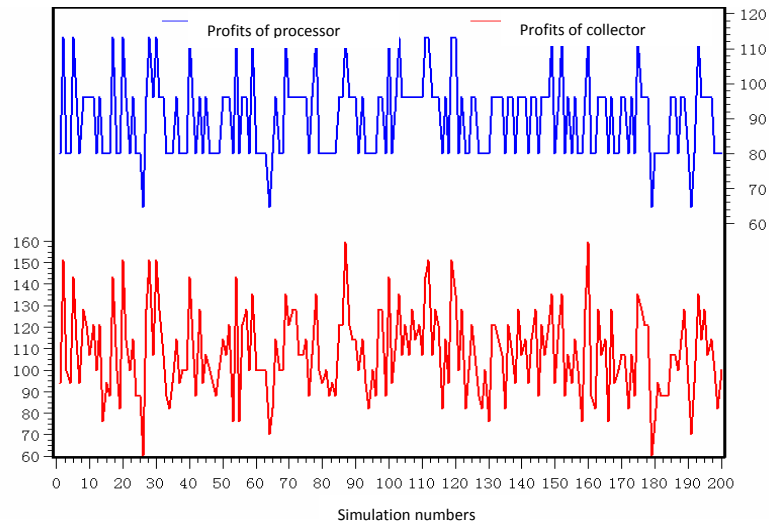
**Figure 5: Option contract coordination model**

As shown in Figure 5, the option price that collector promises to processor is  $M$ , and it charges  $o = \lambda \rho_p((1 + \lambda)q_r, q_p)$ , ( $0 \leq \lambda \leq 1$ ). In this scheme, both parties have their income compensation schemes, and collector is motivated to increase its e-waste supply, and therefore their order, it is shown in the price function  $\rho_p = \rho_p(a \cdot q_r, b \cdot q_p)$ , where  $a = (1 + \lambda) > 1$ . When the option expires, processor sells raw material to producer at the price  $\rho_D(\alpha q_p, D)$ , which is decided by the market supply and demand. Also,  $\rho_D(\alpha q_p, D)$  and  $M$  are compared, if  $\rho_D(\alpha q_p, D) < M$ , then processor will exercise the option contract, but not selling raw material to the collector; it will sell the raw material to producer at market price  $\rho_D(\alpha q_p, D) < M$ , and ask for the difference of prices  $M - \rho_D(\alpha q_p, D)$  from the collector. Otherwise, if  $\rho_D(\alpha q_p, D) > M$ , then

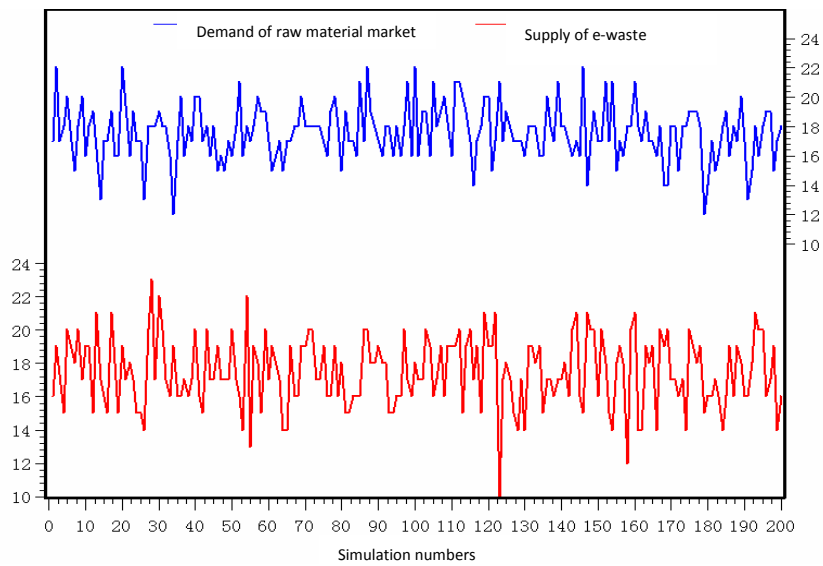
processor will choose not to exercise the option contract. Therefore, an e-waste reverse logistics model based on option contract coordination is as follows:

$$\begin{aligned}
\max \quad & \Pi_r(q_r) = \rho_p(q_r, q_p) \square q_p - \rho_r(S, q_r) \square q_r + o \square q_r - L_r(q_r, q_p) - C_r(q_r) \\
& \quad - \max(M - \rho_p(q_r, q_p), 0) \square q_r \\
\max \quad & \Pi_p(q_p) = \rho_D(\alpha q_p, D) \square \min(\alpha q_p, D) + \max(M - \rho_p(q_r, q_p), 0) \square q_r \\
& \quad - \rho_p(q_r, q_p) \square q_p - o \square q_r - L_p(q_p, \frac{D}{\alpha}) - C_r[\min(q_p, \frac{D}{\alpha})] \\
\text{st:} \quad & S \geq q_r \\
& q_r \geq q_p \\
& q_r, q_p > 0
\end{aligned} \tag{4}$$

With this model, the contract characteristics are stronger, and moral risk is lowered. After processor purchases this option contract from collector, it will decide whether to exercise the option based on market price, meanwhile interest of collector is secured by the income of option contract charge. Thus this contract can be taken as a coordination tool. Following, this contract is imposed to the example in part 3.3, to verify its effect on reverse supply chain. Based on using fuzzy search optimization algorithm and setting that  $S, D$  both follow  $N(18, 2)$  distribution in SAS software, 200 simulations give results shown in Figure 6 and Figure 7.

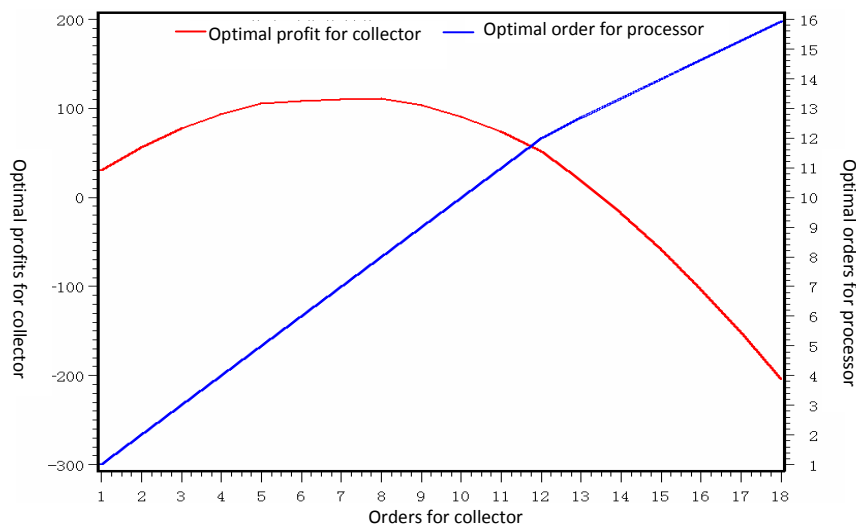


**Figure 6: Optimal profits of collector and processor**



**Figure 7: Optimal orders of collector and processor**

From the simulations, an equilibrium solution to the Stackelberg dynamic game is derived. Average optimal profit for collector is 108.05, and that for processor is 106.61. Both sides keep order at approximately 8, the more the order is, the more the profits are for both parties. In this contract model, collector, processor, and the whole supply chain benefit from the contract. Considering  $S = D = 18$ , analysis gives results shown in Figure 8 and Table 2.



**Figure 8: Decision makings of collector and processor**

From Figure 8, processor and collector achieve equilibrium at  $q_r = q_p = 8$ , since collector is the leader in the game, and its profit is maximized at  $q_r = 8$ . From Table 2, compared with distributed and uncoordinated reverse logistics system, profit of collector increases by 5.75%, and that of processor increases by 7.58%, that for the whole supply chain increases by 6.67%. Also, reclamation efficiency increases by 14.29%, all of which advocates the benefit of option contract coordination model.

**Table 2: Option contract coordination model effect**

	<i>Price</i>	<i>Order</i>	<i>Profit</i>	<i>Profit increase</i>	<i>Reclamation efficiency increase</i>	<i>Option price</i>	<i>Exercise price</i>
Collector	5	8	111.04	5.75%		5.28	38
Processor	17.6	8	112.96	7.58%		5.28	38
Supply chain			224	6.67%	14.29%		

## 5. Conclusion

This paper studies e-waste reverse logistics. Firstly a decentralized supply chain with single collector and single processor is considered, and price function scheme is introduced in, a Stackelberg leader-follower dynamic game model with profit maximization purpose is built. In the model, collector is the leader who decides order quantity from consumer market, distributes e-waste, and sells them to processor. The processor, as the follower, decides its own order quantity, processes e-waste, and sells the converted raw material to producer. Prices at which both collector and processor buy are determined by the market supply and demand. This paper applies two-level programming model to study pricing decision making in a Stackelberg game

circumstances, and gives fuzzy search optimization algorithm.

Also this paper studies centralized reverse supply chain. The analysis shows that decentralized reverse supply chain maximizes players' interest with a stable price in equilibrium, although it does not guarantee optimality for the whole system. Centralized reverse supply chain, on the other hand, maximizes overall interest, but is not stable; processor easily deviates from cooperation, which cause loss to both collector and processor.

Therefore, a coordination scheme is needed, as in the case of forward supply chain. Coordination does not only improve the profit of overall supply chain, it also improve social effects.

Generally, equilibrium solution to Stackelberg game is not Pareto optimal, there is still room for players in the supply chain to improve their profits. The objective of coordination research in reverse logistics is to find motivation to keep the interests of players and that of the system consistent, without damaging the distributed supply chain structure.

The proposed scheme in this paper is a contract model based on option coordination. Option and corresponding charge, as argued in the paper, can enable the interest of players and that of the whole supply chain to be consistent, and thus improve efficiency and profit of reclamation system. As long as collector and processor can communicate and decide appropriate option price and charge, coordination effect can be achieved. The simulations support this argument.

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