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Design for E-Waste Recycling Deposit System and Expense Mechanism in China

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1. Introduction

With 50 million metric tons of e-waste disposed worldwide each year, e-waste recycling has become an increasingly important issue globally. China alone adds 2 million tons of e-waste and the number increases at a rate of more than 10% each year (Ni, 2007). American consumers replace their mobile phones every one and half years on average (Grow, 2008), producing 130 million discarded cell phones annually nationwide (Hanselman, 2007). In China, 70 million mobile phones and 10 million PCs are being discarded each year (NDRC1, 2006). Likewise, more than 50 million PCs are disposed in the U.S. each year (Hung, 2007), with this number accounting for only 10% of the disposable computers. The majorities of defunct computers are not being used and simply collect dust (Zhong, 2009).

Along with the execution of policies and regulations for e-waste recycling, the Chinese National Development and Reform Commission have launched four national pilot projects in four major cities including Hangzhou, Qingdao, Beijing and Tianjin since 2004 (NDRC2). The objectives of the pilot projects include: setting up a network for e-waste collection, supporting the development of standards and regulations for e-waste management, and developing key technologies as well as equipment for Waste Electrical and Electronic Equipment (WEEE) recycling (Yu, 2010, Streicher, 2007). Despite the advanced equipment and technologies supporting the pilot projects, the effect of these pilots was only minimal due to the high cost involved. While typical recycling companies are challenged because of the shortage of supplies, lacking efficient incentive has become a bottleneck of e-waste recycling in China.

To find the best solution to the e-waste recycling issue in China, this research carefully considers and examines recycling models such as Extended Producer Responsibility (EPR), Online Recycling System and the existing Deposit-refund System. After weighing pros and cons of each, it is concluded that we need to explore a new approach under EPR to best suit China's socio-economic situation. We then combine and tailor the concepts of the 3 above-mentioned systems based on China's situation, and proposed a customized deposit-refund system under EPR structure with the facilitation of online information technology. With the deposit-refund system under EPR, it is much easier to increase consumers' incentives to recycle and accordingly ensure the construction of a formal recycling channel.

Surrounding the proposed deposit-refund System under EPR, this research carefully analyzes the correlative monetary, information and product flow for China's e-waste special

fund administration and tries to apply closed-loop supply chain optimization theory to design an expense allocation incentive mechanism that helps make all parties participate the recycling process and track the environment effect. Focusing on the issues of recycling, environmental effects and incentives, and re-evaluation of the appropriate roles of the government, this research provides a new perspective on supply chain analysis. Based on Savasakan's supply chain model, we refer the deposit parameter as a new parameter, and then examine the global supply chain from the angle of total social welfare and environment impact. Lastly, in this research, we try to define and introduce the quantitative and standardization theory, which will greatly enrich and complement the existing recycling theory system for future study.

2. Review of alternative recycling systems

2.1 EPR system

EPR (Extended Producer Responsibility) is defined as "a policy principle to promote total life-cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life-cycle of the product, and especially to the take-back, recycling and final disposal of the product" (Lindhqvist, 1999). EPR requests producers to take responsibility and minimize its negative environmental impacts from designing recyclable products in the first phase (eco-design) to collecting those to be disposed at the end of the products' useful lives (Zhong, 2009). Furthermore, it avoids "everyone's responsibility is no one's responsibility" because it sets forth the overall "polluter pays" principle. As an environmental legislation, EPR has provided a new means to clarify responsibility implementation through administrative, economic, and informational instruments. The concept of EPR was first formally introduced in Sweden. In 2000, the European Parliament passed a directive requiring its member countries to institute an EPR program for EOL vehicles (Forslind K.H, 2005) and an additional directive for WEEE was approved in early 2003. Other countries, such as Japan has also enacted an EPR law covering four large electrical home appliances (Spicer A, 2004). The United States established a similar system with a variation of focusing more on product responsibility, instead of product. Table 1 shows the definition and explanation of EPR under respective legislations.

The ultimate goal of controlling e-waste is minimizing the impact of end-of-lifecycle (EOL) products on the environment. Scholars have explored the practices of EPR in different regions and across different products. They reached a consensus recognizing that EPR policies can actually stimulate product innovation and environment-friendly design in reducing materials, resources and energy usage by eliminating the use of toxins, extending the useful life cycle, increasing opportunities for recovery and re-use of the product at end-of-life (Scott N., 2007,Tojo N., 2001). But all of that is under the condition of higher economic development level, the execution force of legislation and active and positive involvement from consumers. In this model, consumers' incentives to recycle disposed items to a great extent depend on their voluntary will and their sense of responsibility to comply their duties under the EPR legislation. However, in China, pure constraint from legislation alone does not form enough motivation for consumers to perform their duty in recycling process and it is practically hard to ensure the full execution of legislation.

		Europe	Japan	U.S.
legislations		WEEE Restriction of Hazardous Substance (RoHS) Package and EOL Vehicles (ELVs)	Home Appliance Recycling Law	20 states now have laws for discarded electronic products that require producers to finance or manage collection and responsible recycling
Responsibilities	Producer	Collection, recycling, disposal and charging the fee	Complete recycling rate index	In EPR system, producer, supplier and customer take on responsibility for the environmentally appropriate disposal of e-waste
	Consumer	Pay the recycling fee and insure the integrity of e-waste	Inform the retailer when home appliances retire	
	Government	Pay a part of fee of collection, disposable or make policy of fiscal subsidies of EPR organization	Enforce legislation	

Table 1. Definition and legislation of EPR in Europe, Japan and U.S.

On Feb. 25th, 2010, Chinese government promulgated "Regulation of Management of the Recycling and Disposal of Waste Electrical and Electronic Equipment" and it has taken effect as of January 1st, 2011. This scheme, quoting EPR's concept, proposes to establish special fund contributed by producer, retailer and consumer who are responsible for environment prevention and assisting e-waste recycling. However, it will still be a critical issue to enforce this finance system in real practice in the future if the problems of high cost and lack of incentives are not solved.

2.2 Online recycling system

Some scholars proposed a third-party system (Spicer A, 2004, Zhong, 2009). Under this model, Zhong introduced the concept of an online recycling system in China (Zhong, 2010). This online recycling system focuses on building an e-commerce platform to collect and analyze recycling date in real time. Similar to forward logistic shopping website, it only provides recycling related services. With this system, a consumer will only need to submit the e-waste information including the product category, brand, model, purchase date, current condition and etc. via the internet or over the phone. The system will then automatically generate a list of the items to be recycled, which will be picked up by professionals from a third-party recycler. After the transaction, third-party recycler pays the consumer via internet or in cash as compensation. The e-waste will then be transferred to an e-waste recycling center, a third firm dedicated to recovering reusable materials from EOL products and selling them in second-hand markets. Once it has been delivered to the recycling center, the e-waste will first be inspected to determine whether it should be

repaired or disassembled. Repaired products can be sold in second-hand markets, while disassembled EOL products will be segregated into reusable, recyclable, and disposable materials, with each sent to its appropriate inventory. The reusable and recycling components are tested for their usability potential before they are sent to a producer or retailer, and the disposable components are sent to the disposal site. At the same time, the government and producers will provide financial support to recycling center to realize the EPR principle. This system is fast, convenient and can be easily spread once established, but it needs an original power to push this huge e-commerce recycling market and a series of policies and assessment methods such as LCA theory to support the system operation. It requires high capacity for recycling and dispatching and also needs the consistent participation from all consumers and a high reward to the participated consumers. With China's current economic level, and the fact that civic recycling consciousness hasn't been widely established throughout the whole nation, without enough recycling compensation, establishing such a big and complete system can be a long term task and needs us to seek an effective means to achieve it in gradual steps.

2.3 Deposit-refund system in the World

For most pollutants, the standard response of economists is to tax the offending activity. However, a direct tax is not easy to impose on dumping or litter, therefore, an effective alternative is to apply the deposit-refund system (DRS) (Don Fullerton, 2000). With DRS, consumers pay deposits when they purchase items and get refund when they return the items for recycle.

Take beverage container recycling system in United States as an example. Bottle bills require deposits on beverage containers, such as bottles and cans, at the time of purchase. These deposits can be totally or partially recovered by individuals who recycle these containers. When a retailer buys beverages from a distributor, a deposit is paid to the distributor for each can or bottle purchased. The consumer pays the deposit to the retailer when buying the beverage. When the consumer returns the empty beverage container to the retail store, to a redemption center, or to a reverse vending machine, the deposit is refunded. The retailer recoups the deposit from the distributor, plus an additional handling fee in most U.S. states. The handling fee, which generally ranges from one to three cents, helps cover the cost of handling the containers (Yeh, Chiou-nan, 2008).

The beverage container recycling program in the United States is an important representative of a successful deposit-refund system. The system encourages consumers to return beverage containers by providing a refund on the deposit, and is considered by many stakeholders as a successful recycling program to be expanded as a federal policy (U.S. GAO, 2006). The eleven states (California, Connecticut, Delaware, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon and Vermont) employing this system have achieved higher recycling rates and have recycled more beverage containers than the other 39 states combined (DOC, 2007). The refund value of the container (usually 5 or 10 cents) provides a monetary incentive to return the container for recycling (Ramzy, 2008).

Similarly, container deposit legislation is widespread in many countries in the world, such as Australia, Canada, Germany, Netherlands, New Zealand, Denmark, Norway, Sweden,

Finland, United Kingdom, and etc. Even in China, you can find the reverse vending machines that recycle beverage bottle or can and returns 5-10 cents as refund. However, it only provides a channel to encourage consumers' return behaviors.

Although some enterprises and organizations oppose the deposit system, government may pass container deposit legislation for following reasons:

- To encourage recycling and complement existing curbside recycling programs
- To recycle plastic PET (Polyethylene Terephthalate), aluminums that may create more economic value.
- To specifically reduce beverage container litter that pollutes the environment.
- To provide an economic incentive to control and govern environment pollution
- The system is in fact a significant source of income to some individuals and non-profit civic organizations

To summarize, Deposit-refund System can help consumers prevent from polluting the environment. It can also help fund environmental programs and cover the costs of processing returned containers with redeemed capital.

Not limited to beverage area, researchers proposed deposit application in many other fields such as e-waste, battery and auto industries and etc. In recycling area of WEEE, Ramzy tried to establish an e-market for e-waste returned deposit in the US competitive culture context (Ramzy, 2008). For China, Yu proposed a deposit system with shared responsibility to incentivize consumer participation (Yu, 2010) and He (He, 2010) developed a recycling program by constructing deposit refund scheme in battery recovery. However, neither provided elaboration on the detailed implementation of the system.

Through the above introduction, we find that EPR system emphasizes producer's responsibility and requires producer's participation. It is most feasible for developed countries with high socio-economic level and good sense of responsibility from consumers. The fact that China's economic development is still at a lower level and all consumers haven't built up a relatively good sense of responsibility dictates we cannot directly apply the EPR model without customization in China. We need to, instead, seek economic incentives and meanwhile constrain consumers' behavior in order to achieve a satisfying recycling effect.

Online Recycling System, similarly, fully operates on government and producer, but still cannot address the issue of lacking incentives from consumers. Its convenient online process may help encourage consumers to recycle, but still does not provide enough fund to boost up consumers' incentives. Besides, having all procedures online requires high cost and establishment of a series of surrounding systems to complete the process, such as assessment system and reverse logistic system and etc. Again, China's current recycling market lacks original motive to push this system to form the scale.

The existing Deposit-refund system works well in beverage products and does effectively motivate consumer to recycle disposed products. But if applied to electrical and electronic products without any other measures, it may not work as effectively as for beverage products, for e-waste products are different from beverage containers and they require

more complicated process and demand more resources to recycle and reuse. Deposit alone may not be powerful enough to push the recycling process through. We still need producer's involvement to improve products' design to reduce source of pollution, extend the products' life cycle, and increase opportunities for recovery and re-use of the products.

Based on all analysis above, we propose a Deposit-refund System Under EPR, that integrates concepts from the three models and works best with China's socio-economic situation. This system takes account of economic measures and in an eased-up way delegates the recycling responsibility to consumers. It also incorporates the concept of EPR by having producers control and improves the design of the products from the beginning phase. It facilitates the process with certain online platforms and enforces the constraint of consumers' behavior with the regulations of deposit funds. With the current established "home appliance replacements" system, consumers who contact local recycling company will receive pick-up service and qualify for a direct price reduction when buying the new appliances with vouchers from the company, however, the subsidy comes from National and local finance, in this context, the deposit system under EPR is reasonably more cost effective and practically easier to implement in China.

3. E-waste deposit system under EPR

Although EPR system operates very well in western countries, one big obstacle to the adoption of EPR initiatives appears to be the establishment of the fee structure to address the costs involved in e-waste collection, disposal, and management. Take the U.S. for example, nineteen of the twenty states that have passed the e-waste legislation are adopting producer's responsibility, which requires manufactures and vendors to pay for the recycling costs and also provide free recycling to consumers. On the opposite, California switched such financial burden to the consumers (consumer responsibility), charging a $6 to $10 disposal fee on every computer and television purchased (Hanselman, 2007). An often seen dilemma is that producers are not willing to pay for recycling because such costs, very likely, were not being considered in the initial pricing model, on the other hand, consumers are reluctant to take such responsibility because in some states, there are still options to trash e-waste for free, or they may choose not to recycle at all.

Therefore it is necessary to introduce EPR implementation forms, which can be classified into three major approaches: voluntary, mandatory and economic. In terms of capital operation, in Europe, Korea and Taiwan, all funds come from the producers; while in Japan, the capital comes from the consumer. On the other side, the United States emphasizes more on economic benefits rather than legislation. Based on the situations in China, the authors believe that China should pay more attention on economic methods to design the expense mechanism with enough incentive to get all stakeholders participate in e-waste recycling.

As mentioned above, China has enforced the "Regulation of Management of the Recycling and Disposal of Waste Electrical and Electronic Equipment", the counterpart of the EU WEEE Directive in EPR system and very important for the establishment of an entire management framework for e-waste recycling in China (Liu, 2006). Following EPR principle, the regulation

stipulates that e-waste should be collected by multiple channels and recycled intensively by manufacturers of WEEE. A special fund has been set up. The producer and the importer of electronic products shall perform their duty in making contributions to fund for e-waste recycling (Yu, 2010). Given this context and reference to Ramzy's model of e-market for deposit-refund (Ramzy, 2008), we propose a deposit recycling system that emphasizes on incentive collection, at the same time establishing a competitive market for reuse and recycling services, and ensuring all stakeholders to get involved in this system. This special fund should be managed by a special non-profit organization (a foundation) under the supervision of the government and the capital should come from three sources: consumer's deposit in advance, manufacture's recycling disposal fees and government's subsidy.

As illustrated in Figure 1, we proposed an e-waste deposit recycling system under EPR, called Recycling Fund Administration System. It consists of recycling fund and the fund administration information system. When consumer purchases a new product, he/she must pay a deposit to retailer, who transfers the deposit to the foundation and then receives a variable portion when consumer returns unwanted e-products to the third-party recycling company directly or via "home appliance replacements" system. The non-profit organization and the third-party recycling company are the crucial key to the proposed e-waste deposit recycling system.

Further questions we should take into account when implementing this deposit system include: 1) How to allocate the contribution to the funding? 2) How to stimulate producer to realize their duties? What measures should be taken to provide enough incentive?

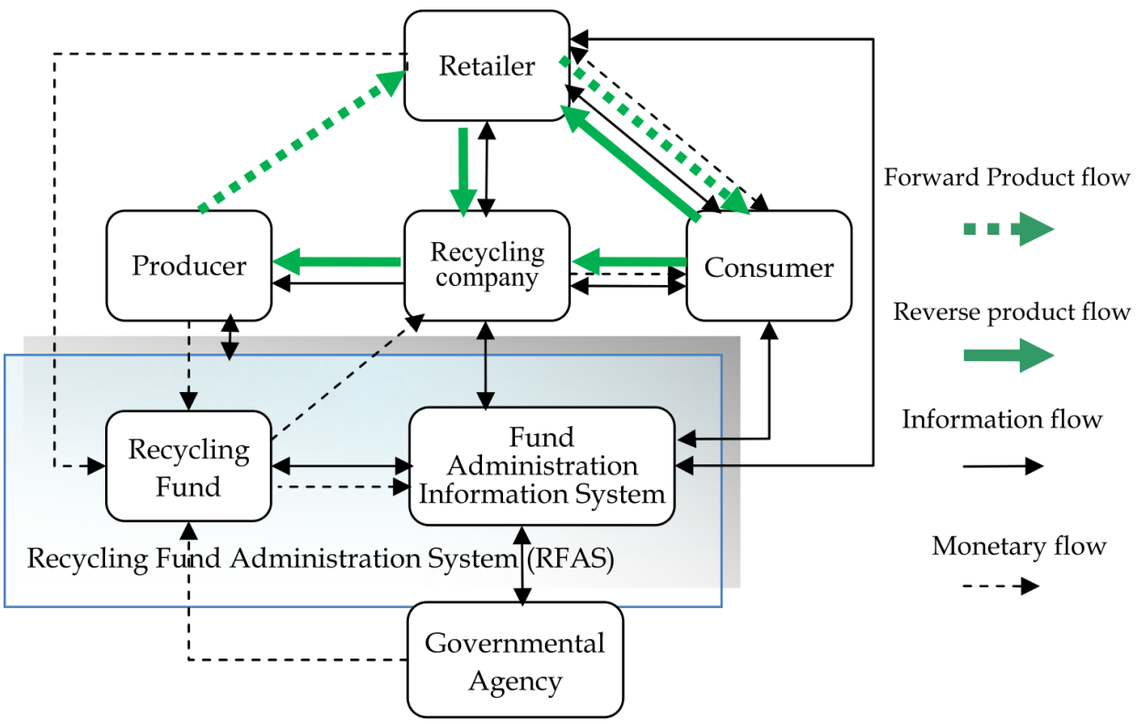


Fig. 1. E-waste deposit recycling system Under EPR

3.1 Monetary flow

To simplify the graphical presentation, we only draw the recycling related monetary flow in this framework, which starts at the point of sale with consumer's payment of the deposits. Then the deposit is transferred by retailer to the foundation, from which the third-party recycling company receives subsidies as reward. The amount varies depending on their processing capability and scalability. When consumer returns his/her unwanted products, he/she has choices to select recycling companies and receive the refund. In the meantime, to abide by the EPR principle, manufacturers and government also need to pay partial of the recycling fee to maintain the foundation's operation.

More details should be covered outside this paper by further research regarding the operations and the management of the deposit system, such as how much manufacturers should pay and how to collect and use the fund; how to determine the amount of the deposit fee; when should recycling companies get subsidy and how to control all recycling flow and manage fund.

3.2 Information flow

Fund administration throughout the deposit system should rely on advanced information technology. Based on the internet platform, the Fund Administration Information System (FAIS) ensures that all information transfers smoothly. Obviously, new electronic product sale system should connect with FAIS when the trade happens. Once consumer wants to return old products, he/she should submit information through two channels – the replace system or contacting FAIS directly. If consumer uses Replacement system of Household Electrical Appliances, he/she can input product information through replacement system which connects to FAIS. Since China has issued Implementation Measures on Replacement of Household Electrical Appliances (also called "home appliance replacements "system) and has already established the recycling database, we can utilize or modify previous information systems rather than rebuilding new ones and save money and resources. If consumer does not purchase new product or there is no replace system nearby, he/she can log into the FAIS website or make phone calls directly to select recycling company to collect their old devices. In the return process, the old electronic product information such as product make, model and year, and consumer's information such as pick-up address or contact, etc. should be inputted to FAIS. FAIS creates a unique code to track each returned product. Meanwhile, the recycling company can give feedback on the level of difficulty of the product disposal and the volume of recycling as an evaluation index of EPR performance of the producer, who also has access to this information. The FAIS's another function is to publish an annual report to ensure the use of specific funding transparent to public.

3.3 Product flow

In the close-loop supply chain, the forward product flow starts from the manufacture. To simplify the process, we do not consider the intermediate suppliers and products directly transferred to the retailer and then sold to consumer. When a consumer decides to discard the old equipment, he/she could select a disposal company by comparing different offers from the competitive recycling market. According to the signed agreement between the

consumer and the disposal company, consumer can freely choose the channel to deliver unwanted product. The returning channel can function in two ways. One way is through the original replacement system channel. It integrates forward and reverse shipping system into one, delivers new product to consumer's location, collects the old returned equipment of the consumer and then finally ships the old equipment to a local collect point where recycling company can pick up later or directly send to recycling company warehouse. This is a way that can save transportation cost and increase logistics efficiency. The other way is through the FAIS channel. Consumer logs into FAIS, submits product information online such as pick-up address, prints the pre-paid shipping label of the recycling firm and drops the product to the shipping company or post office. The deliver policy will differ depending on the competitive recycling company.

4. Design of expense mechanism under e-waste recycling closed-loop supply chain with deposit system

4.1 Summary of recycling pricing coordination mechanism based on supply chain optimization

Utilizing closed-loop supply chain optimization method can help make the mechanism design efficient, establish reasonable price strategies, allocate profits and coordinate all process with all recycling stakeholders having enough participation incentives. Among the recent closed-loop supply chain researches, Savaskan's studies were widely quoted. In his theory, closed-loop supply chain was divided into four models: concentrate coordination, manufacturer collection, retailer collection and third party collection. The four models, in general, can be summarized into 2 categories: decentralized and centralized decision-making models (Savaskan, 2004). Most researches apply Stackelberg's sequential game model and compare the different decision models' efficiency of supply chain based on revenue-expense sharing contract and coordinating mechanism of all stakeholders' interests. Since collection model and supply chain's structures are distinct, different portfolio models were developed by various scholars in the past, as shown as table 2. Additionally, based on Hammod's theory, Wang (2010) comprehensively considered the behavior of the supplier, the manufacturer, the retailer, the demand market and the collector, established the variational inequality models and then developed a remanufacture closed-loop supply chain network equilibrium model. All the researches listed above concentrated on supply chain interest allocation and coordination, but government environmental decision and consumer impetus of participation recycling were seldom referred. In particular, the EPR perspective on cost incentive mechanism related studies was very much lacked. Therefore, it is necessary to extend the research from two aspects. One is to consider government policy maker and focus on environment effects to come up with optimum strategy. The other is to inspire consumer through deposit system to ensure collection effect.

4.2 Savaskan's closed-loop supply chain model by third party collecting

In the original closed-loop supply chain model, Savasakan not only considered 3rd party collecting model (in short 3P model), also compared centrally coordinated system,

<table>
<tr><td rowspan="2">Recycling model / SC structure</td><td>Centralized</td><td colspan="3">Decentralized</td></tr>
<tr><td>Integrated SC Design Models</td><td>Manufacturer collection</td><td>Retailer collection</td><td>Third party collection</td></tr>
<tr><td>2-tier supply chain</td><td rowspan="3">Most of reference focus on comparison between centralized and decentralized decision</td><td rowspan="2">Comparison between manufacturer participating channel, not participating channel and integrated SC (Wang,2007)</td><td>Manufacturer and retailer recycling pricing equilibrium (Ge,2008) Stackelberg and Nash equilibrium cooperation (Gu,2005,Ye,2007) Pricing of close-loop SC considering market segmentation (Wang,2009)</td><td>Retailer selling and third-party collecting (Guo,2007) Manufacturer and recycler games on random collection quantity and capacity constraints (Sun, 2008)</td></tr>
<tr><td colspan="2">Comparison between retailer and third-party collector (Wang,2010)</td></tr>
<tr><td colspan="3">Summarize and compare three recycling models (Fleischmann, 2003, Savaskan,2004, Yao, 2003)</td></tr>
<tr><td>3-tier supply chain</td><td colspan="4">Manufacturers, repair center and retailer's price incentives, Stackerlberg and Nash model comparison (Huang, 2009), Retailer and third-party joint collection, manufacturer, retailer and third-party coordinate pricing by sharing responsibility according revenue and cost share (Zhang, 2010)</td></tr>
</table>

Table 2. Summary of Recycling Pricing Coordination Mechanism Based on Supply Chain Optimization

manufacturer collecting and retailer colleting system. Among the above models, the 3P collecting model as an alternative approach where private companies assume the EOL responsibilities for products on behalf of the original equipment manufacturers and relieves both manufacturers and the general public from the responsibilities and is a promising approach in optimizing product design, specialization, immediate economic feedback and remanufacturing market development (Dan, 2008, Huang, 2006, Spicer, 2004, Xia, 2007, Zhang, 2007, Zhong, 2009). Since Savaskan's model is most widely adopted, we will focus on it in this research, as shown in Figue2.

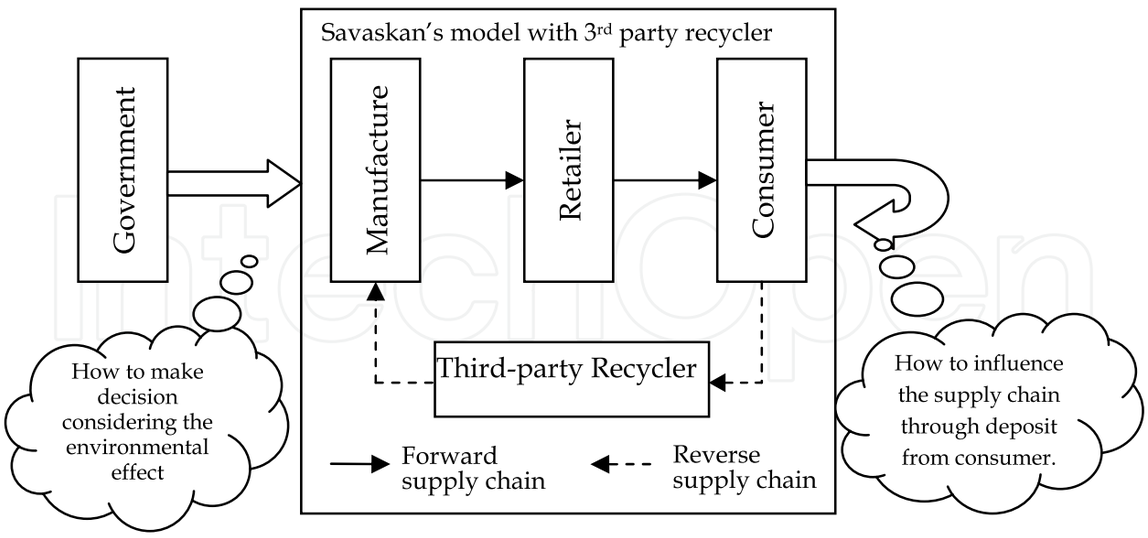


Fig. 2. Closed-loop supply chain system framework with deposit system

Below is a list of notations for Savaskan's Closed-loop Supply Chain Model.

p unit retail price
w unit wholesale price
c_m unit cost of manufacturing a new product
c_r unit cost of remanufacturing a returned product into a new one, assuming $c_m > c_r$
Δ unit cost saving from reuse $\Delta = c_m - c_r$
A fixed payment given to the consumer who returns a used product
C_L scaling parameter
b unit transfer price
$\tau(b)$ the return rate function of used products from the customers which is the expression of the transfer price
$D(p)$ demand for the new product in the market
$D(p) = \phi - \beta p$, with ϕ and β being positive and $\phi > \beta c_m$
Π_j profit function for channel member j, $j \in \{M,R,3P\}$ which denotes the manufacturer, the retailer and the third party

In this 3P model, for a given transfer price b of a used product, the third party maximizes his profits to determine the investment in used-product collection and decides the return rate τ (see Equation1).

$$\max_{\tau} \Pi_{3P} = b\tau(\phi - \beta p) - C_L\tau^2 - A\tau(\phi - \beta p) \quad (1)$$

Retailer solves for price $p(w)$ as a function of the wholesale price set by the manufacturer(see Equation 2).

$$\max_{p} \Pi_R = (p - w)(\phi - \beta p) \quad (2)$$

The manufacturer sets the wholesale price w of the product to Equation (3)

$$\max_w \Pi_M = (\phi - \beta p)[w - c_m + (\Delta - b)\tau] \quad (3)$$

For more detailed and complete model explanations please see Savaskan's paper (Savaskan, 2004).

4.3 The new closed-loop supply model with deposit system

Based on Savaskan's model, our new model has following changes (See Figure 2). Fistly, considering deposit impact for return rate, given d is the deposit of used product, we redefine the return rate function to $\tau(b,d)$. Secondly, we concern more about total supply chain impact when considering the government decision, which accordingly indicates an addition of government function with environment effect.

Through a survey study we can draw a reaction function of deposit change on consumer return wish and then identify the effect on collection rate $\tau(b,d)$. The deposit payment d as new parameter entering the closed-loop supply chain system model plays a key role in the new optimization supply chain model. We should firstly evaluate different deposit payment formats, for instance, a fixed fee or a proportion of the product's price, and then compare how different payment methods of the deposit can influence the rate of collection and cost of recycling. We can use statistical methods and estimate parameters to design a reasonable function to represent the model. Based on the comparison result of different combinations of different approaches and parameters, we can optimize the deposit parameters design in closed-loop supply chain system.

Then we will consider the government decision in closed-loop supply chain that indicates an additional game stage. Government's function should be clarified to satisfy the optimization of manufacture, recycler and consumer and minimize negative impacts on the human environment. For this reason, based on Savaskan's closed-loop supply chain system, we could realize global supply chain optimization by applying the Stackelberg model and maximizing the government utility function, which could be expressed by total social welfare with environment index.

The government solves the deposit d in utility function as follows (see Equation 4):

$$\max_d(\Pi_M + \Pi_R + \Pi_{3P} + \Pi_C + E(\tau)) \quad (4)$$

Π_C indicates the consumer's surplus and $E(\tau)$ is the environment index, the function of return rate.

At the same time, we should compare all stakeholders' interests and supply chain revenue under third party collection in the following situations: 1) whether the government concerns environment or not; 2) whether consumer pays deposit or not; 3) whether manufacturer pays recycling foundation or not; 4) whether manufacturer and consumer pay all together or separately. Accordingly, we can make sure that whether deposit system is practicable and know better how to share the responsibility between producer and consumer.

5. Contributions, limitations and future research

To address the serious issue of e-waste recycling in China, after comparing the different recycling systems in the world, this paper proposes to establish a deposit refund system

under EPR framework suitable to China by providing a clear definition on information, product and monetary flow under the prevailing EPR policy and applying closed-loop supply chain optimization theory. Referring a deposit parameter into supply chain system and at the same time considering the government environment decision, we revise the Savaskan's supply model trying to design an expense allocation incentive mechanism under closed-loop supply chain optimization theory to have all parties participate the recycling process and track the environmental impact. In addition, it provides the quantitative and standardization theory to manage China's e-waste special fund administration. Besides the deposit system the paper also provides another glance of an alternative third-party recycling system that uses the e-commerce information platform to collect and analyze recycling data in real time, and therefore optimizes the design of the supply chain. However, we only give a rough model to solve this optimization problem since the deposit quantitative effect and environment index in government utility function are not clear. Besides, our model is limited to 3rd party collection, and we need to discuss more channels collecting to find the best solution. All these questions need to be analyzed in the future.

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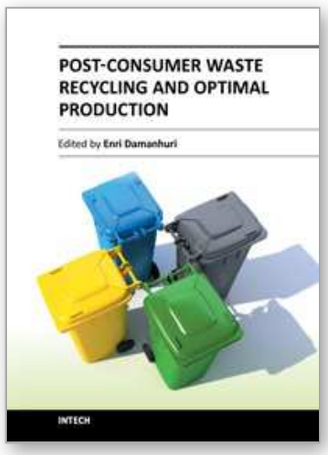
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This book deals with several aspects of waste material recycling. It is divided into three sections. The first section explains the roles of stakeholders, both informal and formal sectors, in post-consumer waste activities. It also discusses waste collection programs for recycling. The second section discusses the analysis tools for recycling system. The third section focuses on the recycling process and optimal production. I hope that this book will convey both the need and means for recycling and resource conservation activities to a wide readership, at both academician and professional level, and contribute to the creation of a sound material-cycle society.

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