Effective Implementation of WEEE Take-back Directive: What Types of Take-back Network Patterns in China

Guojun Ji

Xiamen University, Xiamen Fujian, 361005, China

Abstract

This paper further explains the context of this new legislation and describes, compares and then analyzes the four alternative strategies to reducing end-of-life waste, i.e., repairing, reconditioning, remanufacturing or recycling. It also presents a more robust definition of remanufacturing, which differentiates it from repair and reconditioning engineering. By using a two-stage sequential decision game model, the economic behavior of the main stakeholders under three different types of take-back modes are presented; based on the objective of social welfare maximization, the issues of take-back network, recycling targets setting, recovery catalogs sorting and, supervision and stimulation of take-back models are discussed. Our conclusions demonstrate that: manufacturers, recyclers and consumers do not always share the same preference over three patterns, but the mode of manufacture-leading take-back can reach maximum social welfare; the most efficient network system should be around the manufacturer individual take-back responsibility to build; the take-back level and the recovery catalogs must synthesize the factors involve environmental impact of product, take-back cost/benefit, and recycling and manufacturing industries' market structure etc.; the supervision and stimulation decision matrix associated with the Producer Responsibility Organization is as an effective tool to balance the environmental benefits and social welfare.

Keywords: End-of-life waste; Take-back Directive; Remanufacturing; Extended producer responsibility; Two-stage sequential decision-making game; Producer responsibility organization

1. Introduction

Increasing economic growth has been the principal cause the increase in waste: economic growth reflects increasing production, consumption and thus increases waste. The environmental pressure based on waste generation presents: Firstly, the permanent loss of materials and energy increases day by day. However, whilst it is widely agreed that natural resources will become more expensive due to the need for new excavation/processing technologies, there is little evidence that any natural resources are actually close to running out (Tilton J E, 2003). Secondly, with the current landfill sites are filling up, this leads to pressure to use new sites with the loss of that land use for housing, leisure or agriculture. In England, of the 28.8 million tonnes of municipal waste produced in 2001/2 a higher proportion of 77% went to landfill sites (DEFRA, 2003a). A report has estimated that there is only 6.5 years
of remaining landfill site space left in the UK (Biffa, 2002). Thirdly, the additional waste left in these landfill sites increases air, water and land pollution. For instance, within OECD countries between 25-50% of contaminated areas are as a result of waste activities and 34% of methane emission (one of the 6 greenhouse gases targeted for reduction in the Kyoto Protocol) comes from landfill sites. The European Union has responded by introducing two major policies: a landfill directive and legislation on extended producer responsibility (EPR). Under the EU Landfill Directive (EU, 1999), the UK Government is obliged to closely regulate the issuing of permits for new landfill sites (with the aim of ensuring that better operating standards are in place) and to reduce landfill municipal waste to 33% of its 1995 level by 2020 (principally since the amount of suitable space is running out). One mechanism to achieve this has been a landfill tax charged at £13 per tonne of waste although set to increase to a long-term rate of £35/tonne (HM Treasury, 2002). Extended Producer Responsibility (EPR) is defined by the OECD as “the principle that manufacturer and importers of products should bear a significant degree of responsibility for the environmental impacts of their products throughout the product life-cycle, including impacts from the selection of materials, the production process, and from the use and disposal of the products at the end of life cycle” (OECD, 2001). EPR is the logical extension of the “polluter pays” principle. This rests on the argument that environmental impacts are substantially determined at the point of design where key choices are made—on materials, processing and finishing technology etc., i.e., with the producer (Gertsakis J et al., 2000). This principle has been most clearly implemented in the WEEE Directive on Waste Electrical & Electronic Equipment. In August 2004, EU OEM (Original Equipment Manufacturers) and importers will be legally bound to take significant responsibility for the treatment and disposal of post-consumer products (EU, 2003). The objectives of the WEEE Directive include: reducing the waste arising from end-of-life electrical and electronic equipment (EEE), improving and maximizing recycling, reuse and other forms of recovery of wastes from end-of-life electrical and electronic equipment, and minimizing the impact on the environment from their treatment and disposal. An interesting analysis on the likely effect of the WEEE Directive in the UK concludes that it may only reduce Municipal Solid Waste by 0.1% because high levels of WEEE waste is already recycled (Price Waterhouse Coopers, 2002). But this overlooks the fact that end-of-life waste also generates commercial waste during the production phase for the electrical product. Therefore, if the WEEE Directive was to lead to an increase in product repair and remanufacture, this would in turn reduce all consumer, manufacturing and resource extraction waste. However, regardless of the quantified difference in waste, an undisputed effect of the Directive will be to transfer the cost of waste management from the general taxpayer to the individual OEMs. Although the Directive gives 11 categories of electronic and electrical waste, the presented waste levels reflected that large household appliances (such as fridges, cookers and washing machines) and IT equipment (such as PCs, mainframes, printers, copiers) accounted for 43% and 39% respectively, as well as whilst 88% of large household appliances were recycled, only 40% (approximately) of IT equipment is currently recycled (ICER, 2000). The principle reasons given for this difference were firstly that it is easier to separate large appliances in the waste stream and secondly that it is harder to separate out the ferrous metal from IT equipment.

In view of the WEEE Directive successfully performed in other countries and the current situation of China, the “Management Regulation on the Recycling and Treatment of Disposed Appliances and Electronics Products (MRRTDAEP)” was jointly drafted by six ministries including Ministry of Information Industry, Ministry of Commerce and SEPA in September 2004. The revised version of the Regulation was just approved and will be promulgated by State Development and Reform Commission (SDRC). The new Regulation covers all types of EEE on the market, regardless of whether it is produced in, or imported to, China. This Regulation takes resource recycling and environmental protection as the objective, and practices the extended producer responsibility system. Its main contents are as follows: (1) Local governments shall be responsible for the take-back network and treatment of WEEE and should constitute the corresponding detailed implementing rules; (2) Multiple take-back and centralized treatment of WEEE should be implemented. WEEE recycling firms should be approved and authorized by SEPA; (3) Government should create a special fund for WEEE recycling; (4) WEEE recycling firms shall operate according to market rules; (5) Government promotes and supports WEEE firms by formulating favorable policies and regulations; (6) Manufacturers of PCs, TV sets, mobile phones, DVD players, refrigerators and air-conditioners are required to select environmentally-friendly raw materials for their products and to recycle the discarded ones; (7) Manufacturers will be severely punished if they do not obey the new rules. They could either be fined and/or have their business licenses revoked. The competition in the business of domestic electric appliances is extremely intense in China. The profit per domestic electric equipment is usually trivial. It is hardly performed for the producers entirely to finance the collection, treatment, recovery and disposal of WEEE like EU. Although
China’s economy is rapidly growing, most of Chinese are still not rich. It will be a heavy burden for consumers to pay the necessary fees for collection, transportation and recycling of WEEE like Japan. Hereby state is very cautious when concerning the fee source for WEEE management. With the reference of the successful experience in other countries, the rule of the charge for WEEE management that suits for current situation of China is being studied by Chinese Household Electrical Appliances Association. Specially, China’s State Council promulgated on February 25, 2009, the “Administrative Regulations on the Collection and Disposal of Waste Electric and Electronic Products” (the “WEEE Regulations”), to implement the provisions of the Law on the Promotion of Clean Production and the Law on the Prevention and Control of Environmental Pollution by Solid Waste. The WEEE Regulations have come into effect on January 1, 2011, that complement the “Administrative Measures on the Control of Pollution Caused by Electronic Information Products” (referred to as “China RoHS”), which were promulgated on February 28, 2006, and came into effect on March 1, 2007. The WEEE Regulations are based on China’s practices, and use the experience of other countries “Extended Producer Responsibility” (EPR) for reference, which aims to: (1) Incentive manufacturers to use design for environment (DfE), such as improving products recyclable and reusable; (2) Encourage manufacturers recycling WEEE, reduce the environmental impact of WEEE (Savage, 2006; Mayers et al., 2005). However, the manufacturers are not the only one stakeholder of product environmental responsibility, the effective implementation of the WEEE Regulations and EPR should be based on the prerequisite for the participation and cooperation of the Government, contractors, suppliers, consumers and other sections. The Directive essentially not only shows a trend-the economy and the environment shall receive the coordinative development, but it is an effective measure to promote economic-social-environmental sustainable development. Under the European Directive enterprises are responsible for establishment of their own recovery and disposal schemes (or for sub-contracting such work to commercial producer compliance schemes) and government does not generally provide centralized systems of the type envisaged under the WEEE Regulations.

From above mentioned, there are a number of critical issues have yet to be addressed as follows: (i) The WEEE Regulations do not provide the scope of products to which the WEEE Regulations will apply. They do indicate that they will only apply to products listed in a catalog to be issued by the NDRC, MEP, and MIIT. The Catalog, however, has yet to be provided and, if the delays associated with the similar catalog pertaining to China RoHS are a guide, it could be some time before the final version of the Catalog is issued. In the meantime, the MEP has issued draft Technical Specifications for Processing Waste Electrical and Electronic Products for public comment (MEP Draft Standards). The MEP Draft Standards provide technical standards for the disposal of a range of electrical and electronic products, including computer products, telecommunications products, audio and video products, radio and television products, household appliances, measurement monitoring products, electric tools, wires and cables etc. Although the MEP Draft Standards were issued under prior legislation (and do not therefore expressly refer to the WEEE Regulations), they may nonetheless provide some clue as to the eventual scope of the WEEE Regulations. (ii) Several critical matters concerning the fund also remain open for the MOF to determine, subject to the approval of the State Council, including what entities are required contribute to the fund, and how contribution amounts will be determined. At present, MOF has not proposed any procedure or timeline for consultation with industry participants concerning the details surrounding the fund. (iii) Although both manufacturers and resellers are required to participate under the WEEE Regulations, it is unclear whether manufacturers will be able to implement recovery and recycling programs that cover products distributed by their resellers. (iv) It is currently unclear what percentage of a product will need to be reused in order to apply as a Refurbished EEE. (v) The WEEE Regulations show that the government will formulate regional plans for disposal of EEE. This could need to formulate the multiple regional plans (and, likewise, standards) for reuse and disposal. (vi) It is unclear whether the labeling requirement under the WEEE Regulations will be the same as required under the RoHS. Therefore, to analyze the problem and insufficiency of Chinese present WEEE recovery processing pattern, and use the EPR system implementation experience of other countries for reference, which it has an important theoretical and the practical significance.

At present, China’s WEEE recycling disposals are undertook mainly by some informal sectors, they not only waste resources but also pollute the environment and even face the occupational safety. At the same time, without enough WEEE recycling, then it results in the official processing firms “await urgently necessary condition”, which they involve in the red state. Therefore, the government should develop and implement the feasible legislation to regulate the WEEE recycling industry. From the consumer behaviour, if the customer behaviours are willing to returns, then would help the home appliances recycling; From the manufacturers, the home appliance firms recycling behaviours were systematically analyzed (Wang ZH et al., 2008); From Producer Responsibility
Organizations (PROs) perspective, Mayers (2007) based on a case of SONY Computer Entertainment in Europe, presented the PROs have the important role under the EU WEEE regulations; From the recycling firms, according to reverse logistics process of the waste computers, under without any laws support was shown the firms’ benefit is less, so the government should promote the circulation economic legislation as soon as possible and to promulgate; From the government's perspective, the environment subsidy policies shall effect on the firms decision-making environment as well as the government may institute the subsidy contract to motivate remanufacturers (Mitra S et al., 2008). From the quantitative models reflect: Savaskan et al. (2004) from the manufacturer's decision-making to establish quantitative models of three reverse logistics operation (retailer take-back, third-party take-back, and manufacturer take-back), then they found the basic properties of the three models optimization; Subramanian et al. (2009) under the WEEE regulations, analyzed a supply chain how to coordination can lead to remanufactured products of better DfE; Atasu A et al. (2009) presented the impact of product reuse design and “pick-up” patterns based on two PROs models, which found that individual take-back model has better stimulation than the collective take-back model; Toyasaki et al., (2008) based on the manufacturing and processing industries characteristics, by using two-stage game models, presented the individual take-back model and the collective take-back model to the stakeholders reflect the different impacts, and figured that the PROs are critical to the recovery system, but the manufacturers themselves disposal capacity is omitted. Atasu et al. (2009) based on the social welfare maximization objective to balance economic and environmental impacts, in order to ensure the fairness of implementation the WEEE regulations, but there is shortage of comparative analysis on the take-back and disposal models. Different with the above literatures, we will integrate various essential factors to bring into the WEEE regulations system, thus obtain to the whole understanding of the PROs roles and the stakeholders.

The structure of this paper is organized as follows: section 2 analyzes the practical solutions in China. Section 3 presents the return loop design. Section 4 discusses Models of Assumptions. Section 5 analyzes and compares the take-back models. Section 6 reveals the effective implementation of the WEEE regulations.

2. Return Loop Design

There are still some problems that restrict the operation of qualified WEEE recycling firms in China. Globalization has been realized on a very high level with relations between suppliers from different continents. Consequently, the ever-increasing WEEE has become a global problem. Resolving the problem and thus improving the sustainable development of the electronic industry in China require extensively international cooperation not only in technologies, but also in management, knowledge exchange, and education, etc. However, in Asia and the Pacific region (including China), despite the initiatives by some of the countries, agencies with the mandate on waste management in the region generally have no specific knowledge of the composition of WEEE and their management; and lack communication, information exchange, and corresponding cooperation among them. So it is necessary to promote WEEE management in Asia and the Pacific region by initiating a regional level activity for knowledge sharing under the direction of UNEP. The application for setting up “Asia-Pacific WEEE Database and Management Center” has just been approved by UNEP, and the center will soon be established in UNEP-Tongji Institute of Environment for Sustainable Development. Main activities are as follows: (1) Collecting information regarding WEEE in Asia and the Pacific region and establishing corresponding database; (2) Organizing annual international conferences of WEEE to exchange related information; (3) Analyzing the performance and logistic aspects of WEEE management systems currently implemented in the European Union, the United States, Japan and so on, and then investigating regulations, policy and byelaw about WEEE management fit for the local status to service related office; (4) Organizing international forum on recycling technology of WEEE in order to introduce successfully applied cost-effective and environmentally friendly technologies to Asia-Pacific region; (5) Inspecting the operation of introduced technologies and organizing researchers to make innovation with finding problems.

Further, the end-of-life domestic electric appliances, such as TV sets, refrigerators and washing machines, are not wastes, but merchandises for most of their holders in China. Generally, the “merchandises” are collected by hucksters. Most of them are sold to the countryside after simple repair or maintenance. What can no longer be reused are dismantled manually, and then processed in unqualified household workshops or small factories for recovery of valuable components and materials. In these household workshops or small factories, the recovery processes are carried out with inappropriate approaches, regardless of the corresponding impact on environment and health of the operators, so their recycling costs are much low. By contraries, the qualified recycling plants have
advanced recovery technologies, and proper environmental and healthy protective measures that their operation costs are high. Compared with these household workshops or small factories, the fare paid for collection of the end-of-life domestic electric appliances is a heavy burden for these qualified recycling plants. Before the enforcement of the legislations on WEEE, above unqualified household workshops or small factories could not be forbidden completely. Consequently, the competition for collection of the end-of-life domestic electric appliances can hardly be put to an end. Besides, the charges for processing waste domestic electric appliances are now paid by recycling companies themselves. As a result, the total charge including the fares for collection and processing is usually higher than the income gained from selling the reusable secondhand products and valuable recovered materials for a qualified WEEE recycling company. For example, the actual situation of Hangzhou Dadi Environmental Protection Company shows that the average fare for collection and treatment of TV sets is about 120 yuan per unit, while the income gained from selling corresponding valuable reclaimed materials is about 50 yuan per unit.

Returning to the idea of closing loops, i.e., repairing or remanufacturing products ought to be more common (if it is more profitable) than recycling. And yet, the reality is the opposite: recycling is far more common that repair or remanufacture. This was seen to be the greatest policy barrier to initiate new remanufacturing schemes. One approach is to establish distinct brand selling lower price products, although the most common approach is to develop Product-Service-Systems (PSS), i.e., involves providing customers with a service rather than a bought product such that it is leased or hired. Thus, manufacturers can return used products for remanufacturing and then reintroduce them into the market.

3. Assumptions of Models

From the recycling pilot firms in China, the pilot effects reflect: (1) A recycling industrial road is explored, which conforms to China’s conditions, the extracted experience will help to institute China’s recycling industrial standards; (2) The management organizations similar to PROs are engendered; (3) The national WEEE take-back network systems can be established (Yang JX et al., 2008). As Figure 1 shows that clearly describes a collection of elements and processes under the WEEE regulations.
Our decision sequence is as follows: the PROs determine recovery rate \( c \), which it means recovery rate after sale, reuse rate \( r \) denotes recycled products can reuse ratio (Tojo N et al., 2001), and \( d \) denotes the subsidies of recovery and processing; based on the cost of recovery and processing, manufacturers determine their products sales volume and price; each processing firm decides to charge a processing fee to manufacturers; and finally, the consumers purchase remanufactured products, where, \( 0 \leq c, r \leq 1, d \geq 0 \). The roles under the WEEE regulations reflect as follows: PROs are the nonprofit organizations, which dominated by the Government and constituted by the producers, industrial associations and the processing firms and so on, shall monitor the producers to bear the responsibilities and obligations of WEEE recovery. Usually they are organized by product category, so the maximum efficiency of concentrative take-back network can be achieved. The Organizations to successful implementation EPR principle play a crucial role. Particularly, when small and medium-sized enterprises involve in the organizations, they can greatly reduce the difficulty and cost of WEEE recovery. And they play a good role with linkage of manufacturers, processors, retailers, governments and other interest groups (Mayers C K., 2007). They are also responsible for expropriation the specific take-back fund to manufacturers, build the recycling standardization system, develop the effective product DfE incentive regulation, enhance consumers' environmental education, etc.

Manufacturers: their main responsibilities reflect: On the one hand, via green production facilitate resources to synthetically utilize and design harmless processing programme, convenient for take-back materials must reach the minimum \( r \); on the other hand, take-back WEEE by own or outsourcing, must reach the minimum \( c \). Manufacturers through two ways complete their WEEE management responsibilities (Toffel M W, 2003), i.e. individual take-back responsibility and collective take-back responsibility. Individual take-back responsibility refers to the manufacturers have own recycling network, is responsible only for take-back own manufactured products; the collective take-back responsibility is aim at all manufacturers product of one profession, manufacturers pay determinate take-back costs to PROs who take on the recycling responsibilities. Assume that there are two identical manufacturers, both utilize the Cournot game to get their market share (see Figure 2), then
\[
p = 1 - \sum_{i=1}^{2} q_i \quad (i = 1, 2,) \quad q_i \text{ is the manufacturer } M_i \text{ sales products. Manufacturers are responsible for take-back waste products manufactured by themselves, and then decide to dispose those whether by themselves or by the qualified processing enterprises. Assume that manufacturers per unit cost of production is } \mu , t \text{ is unit cost of take-back WEEE, and } 1 - \mu - tc > 0 . \text{ When the manufacturers dispose by themselves, can obtain subsidies } d \text{ of unit.}
\]

Treatment providers: under outsourcing take-back mode (see Figure 6), there are two kinds of market structures in the recycling industry: the individual take-back model reflects Cournot competition and the collective take-back model reflects monopolistic competition. Under latter kind of situation, the recovery processing providers, through the game to determine the processing expenses, where the recovery processing cost \( \eta \) (Xie J et al., 2003) includes the disassembling costs of waste product, the remanufacturing costs, landfill and collecting costs, etc.

We do not consider the economies of scale of recovery processing. Suppose that recovery processing providers may obtain the income \( e \) from reusable product. In outsourcing take-back model, the recovery processing providers can receive the unit processing profit is \( t \) from the manufactures. To guarantee the recovery processing providers profitable, so \( t + er - \eta \geq 0 \). Let \( \rho = \eta - er \) denotes the net cost of recovery processing, generally, \( \rho \geq 0 \), the reason may reflect in the recovery processing's costs and benefits of pilot projects (see Table 1).

Suppose further that: (1) The processing provider and recovery provider is regarded as one, i.e., the processing provider's work includes take-back and processing of WEEE; (2) Social surplus (welfare) meets linear additive condition, i.e., the social welfare \( SW = \eta \) equal to manufacturer's profit recovery processing providers’
profit + consumer’s surplus + environmental protectional benefits - Government expenditures.

\[ \text{Provider (} R_A, R_B \text{)} \]

Outsourcing take-back

\[ (M_1, R_1, t_1, R_2, t_2) \]

Model-I

Manufacturers \( M_1, M_2 \)

\[ (M_1, t), (M_2, t) \]

Model-C

Individual take-back

\[ (M_1, drc), (M_2, drc) \]

Model-T

Fig. 2. Two-stage sequential decision-making game

Table 1. Formal take-back costs and benefits of Pilot projects

<table>
<thead>
<tr>
<th>Catalog of recycling product</th>
<th>Disposal cost ①</th>
<th>Disposed value ②</th>
<th>Net processing cost ③</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Take-back cost</td>
<td>Transportation cost</td>
<td>((\text{③}=\text{①}-\text{②}))</td>
</tr>
<tr>
<td>TV set</td>
<td>156</td>
<td>14.5</td>
<td>20</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>165</td>
<td>38.7</td>
<td>172</td>
</tr>
<tr>
<td>Air-condition</td>
<td>308</td>
<td>30.8</td>
<td>100</td>
</tr>
<tr>
<td>Washing machine</td>
<td>115</td>
<td>19.3</td>
<td>40</td>
</tr>
<tr>
<td>Computer</td>
<td>150</td>
<td>47.3</td>
<td>200</td>
</tr>
</tbody>
</table>

4. The analysis of take-back models

At present, there are two major types of WEEE take-back models in China: one is the outsourcing take-back model, which can be divided into single take-back model and collective take-back model; another type is manufacturer internalization take-back model, i.e., recovery and processing by itself (Toffel M W, 2003).

4.1. Outsourcing take-back model

In this model, suppose that the processing provider is as a Stackelberg leader, the manufacturers are followers. This is just as the current WEEE recovery demand of in the Europe far exceeds the existing recovery capacities, the recycling industry is still in the developing phase, at the same time the manufacturers must meet the minimum requirements of the WEEE directive. For example, in Germany there are about 20 recycling firms provide take-back service of old computers and old electrical product to more than 20,000 manufacturers and importers. Similarly, in Netherlands, not-for-profit organizations through four recovery firms to process the waste products of more than 1200 manufacturers and every recovery firm is only responsible for a specific product category (see European WEEE schemes. 2003). In fact, as shown in Figure 6, on the one hand, manufacturers face to compete in the new products market, on the other hand, processing firms set competitive recovery costs in the waste product market.

(i) The collective recovery processing

From model C shown in Figure 6, based on wastes of all manufacturers in one profession, PROs usually according to the profession’s average processing cost collect the manufacturers processing fund. The manufacturers \( M_1, M_2 \) separately sign a contract with PROs and pay the processing cost \( t^C \), then PROs assign the third party
processing provider $R$ to operate and pay the processing fund $t^C$. For instance, Holland, Sweden often use this model.

Therefore, the profit function of the processing provider and the manufacturer are follows, respectively:

$$\Pi^C_R(t^C) = (t^C + er - \eta)c \left( \sum q_i \right) \quad i = 1, 2. \quad (2)$$

$$\Pi^C_i(q_i) = q_i \left( p - u - t^C c \right) \quad i = 1, 2. \quad (3)$$

To reverse deduce the two-stage game, considering the manufacturer Cournot game in the second stage, when given $t^C$, manufacturer $M_1$ determines its output $q^C_i (q^C_2)$ from (3), then the specific response function meets:

$$q^C_i (q^C_2) = \frac{1 - q^C_2 - u - t^C c}{2} \quad (4)$$

Similarly, manufacturer $M_2$ response function can be deduced. Uniting two functions, Nash equilibrium solutions follow:

$$q^C_i (t^C) = \frac{1 - u - t^C c}{3} \quad i = 1, 2. \quad (5)$$

Let (5) substitutes for (2) in the first stage, the processing provide $R$ follows the oligopolistic games, then:

$$t^C = \frac{1 - u - cer + c\eta}{2c} \quad (6)$$

Let $t^C$ substitutes for (5), the equilibrium output and the market price of the product reflect as follows:

$$q^C_i = \frac{1}{6} (1 - u + cer - c\eta) \quad i = 1, 2. \quad (7)$$

$$p^C = \frac{2}{3} + \frac{1 - u - cer}{3} + c\eta \quad (8)$$

At the same time, we can obtain the manufacturer’s profit, processing provider’s profit, consumer’s surplus as well as the system profit, where the system profit $\Pi^S$ is defined as the sum of manufacturer’s profit, processing provider’s profit and consumer’s surplus (see Table 2).

(ii) The single recovery processing

From model I shown in Figure 6, each manufacturer freely signs a contract with single processing provider, in which case PROs are in the supervision role, such as Germany and Austria tends to this model. Assume that manufacturer $M_1$ signs a recovery processing contract with processing provider $R_A$, and pays unit processing expense $t^I_1$ to $R_A$; manufacturer $M_2$ signs a contract with processing provider $R_B$, and pays unit processing expense $t^I_2$ to $R_B$. Then, the profit functions of the processing providers reflect as follows, respectively

$$\Pi^I_A(t^I_1) = \left( t^I_1 + er - \eta \right) cq_1 \quad (9)$$

$$\Pi^I_B(t^I_2) = \left( t^I_2 + er - \eta \right) cq_2 \quad (10)$$

The manufacturers profit functions satisfy:

$$\Pi^I_i(q_i) = q_i \left( p - u - t^I_i c \right) \quad i = 1, 2. \quad (11)$$

To reverse deduce a two-stage game, considering the manufacturer Cournot game in the second stage, when given the unit processing expense $t^I_i$, the manufacturer $M_1$ can determine its output $q^I_i (q^I_2)$, then the response function meets:

$$q^I_i (q^I_2) = \frac{1 - q^I_2 - u - t^I_i c}{2} \quad (12)$$
Similarly, the manufacturer $M_2$ response function can be deduced. Uniting two functions, Nash equilibrium solutions follow, respectively:

$$q_1'(t_1', t_2') = \frac{1-u+t_1'c-2t_1'c}{3}$$  \hspace{1cm} (13) \\
$$q_2'(t_1', t_2') = \frac{1-u+t_2'c-2t_2'c}{3}$$  \hspace{1cm} (14)

Let (13), (14) substitutes for (9) and (10), respectively, considering Cournot game, then the equilibrium solutions of processing expense satisfy:

$$t_i' = \frac{1-u-2cer+2c\eta}{3c} \quad i = 1, 2.$$  \hspace{1cm} (15)

Thereby, the equilibrium output and price of the manufacturers are as follows:

$$q_i' = \frac{2}{9}(1-u+2cer-c\eta) \quad i = 1, 2.$$  \hspace{1cm} (16)

$$p_i' = \frac{5}{9} + \frac{4}{9}u - \frac{4}{9}cer + \frac{4}{9}c\eta$$  \hspace{1cm} (17)

Therefore, in this mode, we can obtain the manufacturer’s profit, the processing provider’s profit, the consumer’s surplus as well as the system’s income (see Table 2).

4.2. The individual take-back model

As shown in Figure 6, model T is a closed-loop supply chain, not only includes the forward flow of the manufacturer's product, but the reverse flow of waste product from consumers. This model is actually internalization and integration of recovery processing, which the manufacturer by oneself fulfil take-back responsibility or the WEEE regulations. For example, IBM and DELL have used the model (Toffel M W, 2003). The model can be performed by the third party providers as well as in virtue of retailers “trade new good for old” way etc. In this model, Government usually gives certain subsidies to manufacturers to encourage them take-back WEEE. Then, manufacturer's profit includes sales’ profit, profit from processing WEEE as well as subsidies, as follows:

$$\Pi_i^T = q_i'(p - u + erc - c\eta + drc) \quad i = 1, 2.$$  \hspace{1cm} (18)

Thereby, the manufacturer through Cournot game, the Nash equilibrium of sales volume and prices satisfy:

$$q_i^T = \frac{1}{3}(1-u+ner-c\eta+drc) \quad i = 1, 2.$$  \hspace{1cm} (19)

$$p_i^T = \frac{1}{3} + \frac{2}{3}u - \frac{2}{3}ner + \frac{2}{3}c\eta - \frac{2}{3}drc$$  \hspace{1cm} (20)

At the same time, we can obtain the manufacturer's profit, consumer’s surplus and the system’s profit in the model (see Table 2).

<table>
<thead>
<tr>
<th>Table 2. Optimal value of three take-back scheme</th>
</tr>
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<tbody>
<tr>
<td>Model C</td>
</tr>
<tr>
<td>Processing fee $t$</td>
</tr>
<tr>
<td>Product price $p$</td>
</tr>
</tbody>
</table>
Product sales $q$

$$\frac{1}{3} (1 - u + cer - c\eta) \quad \frac{4}{9} (1 - u + cer - c\eta) \quad \frac{2}{3} (1 - u + cer - c\eta + drc)$$

Manufacturer’ profit

$$\Pi_M \frac{1}{18} (1 - u + cer - c\eta)^2 \quad \frac{8}{81} (1 - u + cer - c\eta)^2 \quad \frac{2}{9} (1 - u + cer - c\eta + drc)^2$$

Processing provider’s profit $\Pi_R$

$$\Pi_R \frac{1}{6} (1 - u + cer - c\eta)^2 \quad \frac{4}{27} (1 - u + cer - c\eta)^2$$

Consumer’ surplus $\Pi_C$

$$\Pi_C \frac{1}{18} (1 - u + cer - c\eta)^2 \quad \frac{8}{81} (1 - u + cer - c\eta)^2 \quad \frac{2}{9} (1 - u + cer - c\eta + drc)^2$$

System’s profits $\Pi_S$

$$\Pi_S \frac{5}{18} (1 - u + cer - c\eta)^2 \quad \frac{28}{81} (1 - u + cer - c\eta)^2 \quad \frac{4}{9} (1 - u + cer - c\eta + drc)^2$$

By comparing optimum values in Table 2, we have the following Propositions.

Proposition 1: If $t^C > t_i^T$, it will mean that the average processing costs of the collective recovery model is always greater than the single recovery model; If $\Pi^C_R > \Pi^T_R = \Pi^T_A + \Pi^T_B$, it will indicate that processing providers prefer the collective recovery model.

It is easy to see due to lack of competition and motivity of reducing cost, none but those monopoly processing providers have a better scale economy, they will collect a quite low expenses, i.e., only in the perfect recycling market, the recovery processing costs will be reduced. The EU experience of take-back packaging has demonstrated (Savage, M, 2006), when introducing the competition mechanism to the recovery processing industry, the processing cost will be reduced obviously.

Proposition 2: If $p^C > p^T > p^T$, $\Pi^C_i > \Pi^T_i > \Pi^C_i$, it will show that consumers prefer the manufacturers themselves take-back model.

In general, manufacturers’ processing funds are charged can be compensated by three ways: part price transfers to the consumers, profit from the recovery processing as well as the government subsidies. In T model, the processing funds have less impact on the equilibrium price, and the recovery processing cost-sharing to consumers is also less.

Proposition 3: If $\Pi^T_i > \Pi^T_i > \Pi^C_i$, it will indicate that the single recovery model is optimal for manufacturers; If $\text{min}(\Pi^M_T, \Pi^T_M + \Pi^T_R) \geq (\Pi^C_M + \Pi^C_R)$, it will show from the take-back incentive effect of the manufacturers, the single recovery model is better than the collective recovery model.

In reality, Proposition 3 will reflect the recovery processing should pay more attention to the manufacturer participated fashion and their role, i.e., should encourage manufacturers to participate in take-back network; take full advantage of the manufacturers channels, encourage retailers via trade-in or deposit to recycle waste product etc.

Proposition 4: If $\frac{\partial t^C}{\partial r} < 0$, $\frac{\partial t^T}{\partial r} < 0$ and $\frac{\partial t^C}{\partial r} > \frac{\partial t^T}{\partial r}$, it will show that in outsourcing take-back model, the manufacturers improving the reuse rate can reduce the processing costs, and the incentive of single recovery responsibility is more stronger than the collective recovery responsibility; If $0 < \frac{\partial \Pi^C_M}{\partial r} < \frac{\partial \Pi^T_M}{\partial r} < \frac{\partial \Pi^T_R}{\partial r} = \frac{2}{3} q^T c(d + e)$, it will indicate that T model can better motivate manufacturers to improve reuse rate, In particular, when government gives subsidies.

Proposition 5: If $\Pi^C_S < \Pi^T_S < \Pi^T_S$, from the profit maximization of the recycling system, it will show that optimal model is T, next is model I, the worst is model C.

It is easy to see from Proposition 1, 2, 3, to consumers, treatment enterprises, manufacturers and other stakeholders, the preferences of take-back models are inconsistent, so coordinating the incentive of all stakeholders is almost impossible. However, whether they incent to take-back waste products (Proposition 3) or incent to product
design (Proposition 4), our conclusions show that T model is optimal, and according to the results of Proposition 5, PROs should first select T model, which manufacturers select individual take-back model, followed by mode I, the worst is model C.

5. The effective implementation of the WEEE regulations

Considering PROs have selected the optimal take-back model T, by using the recovery rate $c$, reuse rate $r$ and subsidies $d$, we can restrict or incent the recycling behaviour of manufacturers to achieve social welfare $SW$ maximization, and balance economic and environmental impacts (Atasu A et al., 2009). The social welfare implicated by those factors should include the following items: Subsidy expenditure: to encourage manufacturers to take-back WEEE, PROs pay the manufacturers unit subsidy $d$, then the total subsidies are $d \sum q_i^T$.

Environmental benefits (costs): Only when the firms explicitly bring environmental protection costs into their product design and production, then they are considered as environmentally friendly design. Usually, per unit product contains hazardous substances to harm our environment. The environmental impact or processing cost of the substances is defined as the environmental protection cost $\varepsilon$. And assuming that the cost can be monetized (Atasu A et al., 2009). Where there is harmful to the environment, involve not recycled part $1-c$ and not use port $(1-r)c$ after recovery processing, so the environmental protection benefit follows:

$$\Pi_E = -\varepsilon (1-rc)(\sum q_i^T)$$ (21)

In this way, the social welfare function reflects:

$$\max_{c,d} SW(c,d) = \Pi_M + \Pi_C + \Pi_E - drc \sum q_i^T$$

s.t. $0 \leq c \leq 1$ \hspace{1cm} (22)

$d \geq 0$

Since reuse rate $r$ is close related with the production technology, we suppose that $r$ is exogenous variables and $r = 1$, i.e., full reuse. Let $\rho = \eta - er$, we have the following Proposition 6:

Proposition 6: If $\rho \geq \frac{1-u}{3}$, when $\varepsilon \geq \rho$, then we have $c = 1, d = \frac{1-u-\rho}{2}$, and when $\frac{4}{3} \left(1-u+\rho\right) \leq \varepsilon < \rho$, we have $c = \frac{4\rho - 4u\rho - 3\varepsilon + 3\varepsilon u - 3\varepsilon \rho}{2\rho(2\rho - 3\varepsilon)}, d = 0$; If $\rho < \frac{1-u}{3}$, when $\varepsilon \geq \rho$, we have $c = 1, d = \frac{1-u-\rho}{2}$, and when $\varepsilon < \rho$, we have $c = 0, d = 0$.

Proof: Since

$$\max_{c,d} TW(c,d) = \Pi_M + \Pi_C + \Pi_E - drc \sum q_i^T$$

s.t. $0 \leq c \leq 1$ \hspace{1cm} (23)

$d \geq 0$

Let substitute the manufacturers’ profits, consumers’ surplus and environmental protection benefits and subsidies into the above objective function, since $r = 1, \rho = \eta - er$, the overall welfare function $k$ follows:

$$k = \frac{4}{9} (1-u-(\rho-d)c)^2 - \frac{2}{3} \varepsilon(1-c)(1-u-(\rho-d)c) - \frac{2}{3} dc(1-u-(\rho-d)c)$$

s.t. $c \geq 0$

$$1 \geq c$$
When \( d = 0 \), the generalized Lagrange function meets:
\[
L = \frac{4}{9} (1 - u - \rho c)^2 - \frac{2}{3} \varepsilon (1 - c)(1 - u - \rho c) + \lambda c + \beta (1 - c).
\]

Based on KKT conditions, the local optimal values can be gained. Considering the following three situations:

1. \( c = 0 \Rightarrow \lambda \geq 0, \beta = 0 \), then for \( \varepsilon \leq \frac{4}{3} \frac{(1 - u)\rho}{1 - u + \rho} \), we have \( c = 0, d = 0 \); and the local optimal value is
   \[
   k(1) = \frac{4}{9} (1-u)^2 - \frac{2}{3} \varepsilon (1-u).
   \]

2. \( c = 1 \Rightarrow \beta \geq 0, \lambda = 0 \), then for \( \varepsilon \geq \frac{4\rho}{3} \), we have \( c = 1, d = 0 \); and the local optimal value is
   \[
   k(2) = \frac{4}{9} (1 - u - \rho)^2.
   \]

3. \( 0 < c < 1 \Rightarrow \beta = 0, \lambda = 0 \), then for \( \frac{4}{3} \frac{(1 - u)\rho}{1 - u + \rho} \leq \varepsilon \leq \frac{4\rho}{3} \), we have
   \[
   c = \frac{4(1-u)-3\varepsilon(1-u+\rho)}{2\rho(2\rho-3\varepsilon)} \quad \text{and the optimal value is } k(3) = \frac{1}{2} \varepsilon^2 (1-u-\rho)^2.
   \]

When \( d > 0 \), the generalized Lagrange function reflects:
\[
L = \frac{4}{9} (1 - u - (\rho - d)c)^2 - \frac{2}{3} \varepsilon (1 - c)(1 - u - (\rho - d)c) - \frac{2}{3} dc(1 - u - (\rho - d)c) + \lambda c + \beta (1 - c).
\]

Similarly,

4. when \( c = 0, d > 0 \), then we will obtain degenerate solutions;

5. \( c = 1, d > 0 \Rightarrow \lambda = 0, \beta \geq 0 \), then for \( \varepsilon \geq \rho \), \( c = 1, d = \frac{1-u-\rho}{2} \), the local optimal value is
   \[
   k(4) = \frac{1}{2} (1-u-\rho)^2;
   \]

6. when \( c \) is inner, \( d > 0 \Rightarrow \lambda = 0, \beta = 0 \), then we have \( c = \frac{-1+u+\varepsilon}{\varepsilon - \rho}, d = \frac{\varepsilon (-1 + u + \rho)}{-1 + u + \varepsilon} \), but from the Hessian matrix
   \[
   |H| = \frac{4}{9} (1 - u - \varepsilon)^2 > 0
   \]
for the overall welfare function \( k \), that means it is not maximum.

Now, we compare these maximum values. It is easy to see \( k(4) > k(2) \), so the local maximum points may be \( k(1), k(3), k(4) \). To compare the size of the three values, we must compare \( \frac{4}{3} \frac{(1-u)\rho}{1 - u + \rho} \) with \( \rho \).

(i) \( \rho \leq \frac{4}{3} \frac{(1-u)\rho}{1 - u + \rho} \Rightarrow \rho \leq \frac{1-u}{3}, \) and

\[
\begin{align*}
  k(4) &\geq k(3) \Rightarrow \frac{4}{3} \frac{(1-u)\rho}{1 - u + \rho} \leq \varepsilon \\
  k(4) &\geq k(1) \Rightarrow \rho \leq \varepsilon \leq \frac{4}{3} \frac{(1-u)\rho}{1 - u + \rho}
\end{align*}
\]

have \( k(4) < k(1) \), and \( k(3) \) is inexistence, then \( k(1) \) is a whole maximum value.
(ii) when \( \rho > \frac{4}{3} \frac{(1-u)\rho}{1-u+\rho} \Rightarrow \rho > \frac{1-u}{3} \), \( k(4) \geq k(3) \Rightarrow \rho \leq \varepsilon \) and \( k(4) \) is inexistence, so \( k(4) \) is a whole maximum value, for \( \rho \leq \varepsilon \); When \( \frac{4}{3} \frac{(1-u)\rho}{1-u+\rho} \leq \rho < \varepsilon \), it is easy to see \( k(3) \) is a whole maximum value. The proof is complete.

Proposition 6 shows the take-back level and catalog requires comprehensive environmental consideration, such as including the costs or benefits of take-back, the market competitive structure of processing industries and manufacturing industries etc. the subsidies bear fruit only if the product is serious harmful to environment and effective recycling fully. Subsidies can compensate part of the take-back costs, but will increase output as well as increase the emission of pollutants. So, the PROs (government) need from two dimensions of the net processing costs and environmental pollution degree to weigh the environmental benefit and social profit (see Figure 3).

(1) Voluntary take-back. Usually, that means products are less environmental pollution, and take-back costs are relatively small, through self-discipline of manufacturers and the consumer's environmental drive to set recycling goals. And without no legal requirement to comply or unmeet recycling targets, firms will not be punished. For instance, carpet take-back in U.S. A (Savage, M, 2006).

(2) Incomplete take-back. That means the product has the slight environmental pollution, but the take-back costs are higher, Government does not give subsidies, so through the incomplete take-back targets to protect the manufacturers or consumers benefits, such as the WEEE in home appliances. The products because of high processing costs, economies of scale have certain requirements, so manufacturers may be outsourced the take-back activities to the professional service provider, especially to small and medium manufacturers, i.e., T model will transforms to I model.

(3) Complete take-back. That means the product has heavy environmental pollution, no matter how high processing cost, it is mandatory take-back by the government regulation, and government gives some subsidies to the processing firm. For example, waste oil, waste paint etc.

In addition, Chinese government shall give attention to some key issues as follows: (1) Chinese government needs to establish several centralized or specialization systems for recovery and disposal of EEE, since China has the vast region. (2) To maintain the centralized systems, EEE manufacturers and import consignees, as well as their respective agents, will be required to contribute to a WEEE Disposal Fund. The mechanics of the fund and the eventual level of contributions required will be determined in accordance with implementing rules to be promulgated by the Ministry of Finance after consultation with the Ministry of Environmental Protection, the National Development and Reform Commission, and the Ministry of Industry and Information Technology, as well as EEE manufacturers and other industry participants. (3) Manufacturers of EEE are required to adopt plans and
designs that facilitate recycling and the use of non-toxic (or low toxicity) materials that can easily be recovered for reutilization. (4) Manufacturers and import consignees of EEE, as well as their respective agents, are required to provide information regarding the concentration of toxic and hazardous substances contained in the EEE and the methods of collection and disposal of discarded EEE. (5) The WEEE Regulations also provide for a new system through which qualified firms can apply for permits to operate recovery and disposal businesses for waste EEE. (6) EEE manufacturers are “encouraged” to undertake collection of waste EEE of their manufacture, or to outsource their distributors, their service agents, or other firms in the business of collection of waste EEE to do so. The WEEE Regulations also provide that those engaged in collection operations should implement multiple channels for collection in order to provide efficient and convenient service to EEE users. (7) The WEEE Regulations state that recovered EEE resold after collection and refurbishment (Refurbished EEE) must meet people health and other mandatory standards and be clearly labeled as “used goods.”

6. Conclusions

Our conclusions demonstrate that: The preferences of three take-back modes for manufacturers, treatment enterprises, consumers and other stakeholders are inconsistent, but from the view of take-back incentive, product design incentives, the system profits, we find that manufacturer’s individual take-back model is optimal. Therefore, the most efficient recycling network system should focus on the manufacturers’ individual recovery responsibility, make full use of their channel advantage, encourage retailers by trade-in or deposit to recycle the waste products, etc.; To determine the take-back level and recovery product catalog, it is necessary to consider the impact on the environment, take-back costs/benefits, the market competitive structure of processing industries and manufacturing industries as well as consumers acceptance degree of environmental costs, etc.; The government must weigh the environmental protection benefits and social benefits. Effective subsidies only utilize in the product has great harmful to environment, and fully take-back. When product has slight pollution, according to the size of the net processing cost, incomplete take-back or the voluntary take-back is considered, respectively.

There are some open problems as follows: (1) collective take-back responsibility and individual take-back responsibility are not opposed absolutely, how to integrate the cost-benefit advantages of the collective take-back and DfE incentives strengths of the individual take-back, such as Japan SHAR? (2) How to use PROs to coordinate the problems in the WEEE regulations, such as the problems encountered by many Ministries’ management in China? (3) How to ensure that manufacturers invest in eco-design and taking into account product take-back? (4) How to use the network of “home appliances deliver to the countryside”, or “trade-in” to solve WEEE take-back problem in wide rural areas?

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