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Abstract

Product and waste take-back is becoming more regulated by countries to protect the environment. Such regulation puts an economic burden on firms, while creating fairness concerns and potentially even missing its primary target: environmental benefits. This research discusses the economic and environmental impacts of Extended Producer Responsibility (EPR) type of legislation and identifies efficiency conditions. It is shown that the right policy would (i) make producers responsible for their own waste to avoid fairness concerns and (ii) favor eco-design producers to create stronger environmental benefits. Furthermore, the efficiency of take-back systems is also driven by environmental classification of products, industry structure and end-user willingness to participate in take-back programs.

1 Introduction

Take-back legislation holds manufacturers responsible for environmentally safe treatment of their products when they return at the end of their life. Under such Extended Producer Responsibility (EPR) legislation, manufacturers are required to provide a system or financial means of collecting and processing the waste stream of used products to control environmental pollution. Responding to increased pressure from green organizations, a number of governmental take-back regulations have been enacted in the world's leading economies. The environmental directives in the European Union (EU) (EC Report2 2005) and Japan (Japan 2005) have been introduced earlier, while the take-back movement is currently spreading in the USA. Green organizations won their first battle on take-back legislation in Maine in 2004, when the state passed the first US take-back law (Woellert 2006). States such as Washington, California (California 2005), and Maryland joined Maine in enacting take-back legislation (www.computertakeback.com) and 19 other states are currently considering legislation.

There are two basic types of take-back directive principles: (i) consumer pays and (ii) producer pays. Under the consumer pays principle, the end-user is directly charged for the costs of environmentally sound treatment of used products. Under the producer pays principle, the manufacturer is responsible for the environmentally friendly treatment of end-of-use products at no cost to the end user. While Japanese and Californian governments have chosen the former, European and Washington governments have opted for the latter principle.

Our focus in this paper is on take-back directives implemented under the extended producer responsibility with manufacturer pays principle. Several European take-back directives, e.g., for batteries, packaging and end-of-life vehicles (see Tables 5, 6 and 7 in Appendix) have been operational for a long time. These directives are likely templates for future legislation in other regions of the world (see www.computertakeback.com). We base our discussion on the European Waste Electrical and Electronic Equipment (WEEE) Directive (EC Report2 2005), as it is the most recently updated one since its initial adoption in 2003.

The WEEE Directive introduces producer responsibilities for electrical and electronic waste. It is based on collection, recycling and recovery targets imposed on all EU member countries (see Table 1). *Recycling* is defined as reprocessing of the waste materials for the original purpose or for other purposes, but excluding energy recovery which means the use of combustible waste as a means of generating energy through direct incineration with or without other waste but with recovery of the heat. *Recovery* on the other hand has a broader definition, which includes recycling of materials and harvesting residual energy content of used products (EC Report 2005). European governments are responsible for ensuring a minimum collection target of WEEE, currently set at 4 kg per capita per year, free of charge to

Table 1: EU Legislation for Waste Electrical and Electronic Equipment (WEEE) for different categories defined by the Directive (percentages of total weight)

Category	Collection Level	Recycling Level	Recovery Level
Large Household Appliances and Automatic Dispensers	To be decided	75%	80%
IT, Telecom and Consumer Equipments	To be decided	65%	75%
Small Household Equipment, Electrical and Electronic Tools, Medical Devices and Monitoring and Control Equipment	To be decided	50%	70%
Lamps	To be decided	80%	80%
Overall	$>$ 4 kg per inhabitant until 2009	-	-

consumers. Then, producers are responsible for proper treatment of all collected products so that the imposed recycling and recovery targets are met. This legislative structure has been designed considering two basic assumptions: (i) by making producers responsible, an economic incentive is created to design more ecological products, and (ii) recycling and recovery of large quantities of waste should lead to a reduction in environmental impact (Mayers et al. 2005).

Unfortunately, the WEEE Directive has faced important implementation problems and it is still unclear to which extent this directive achieves its intentions. The directive is (to be) implemented in 27 countries, and each country has its own system. This stems from the fact that the EU can impose directives on the member countries, but the latter are free to translate those into national laws as they please, as long as they comply with the directive. So, national laws can be stricter, and implementation details may differ substantially. As a consequence, companies struggle with inter-country differences and unclear specifications on how to comply. The need for improvements from the industry's perspective has been evident as producers, treatment providers and regulators formed public forums to discuss implementation problems related to the WEEE Directive. One such initiative has resulted in the WEEE Directive Series held at INSEAD. The INSEAD WEEE Directive Series is a forum composed of producers, treatment providers, legislators, green groups and academics, organizing regular meetings to discuss issues related to the WEEE Directive in a neutral setting (see www.insead.edu/weee).

Because our purpose in this paper is to understand major issues in designing and implementing WEEE-type extended producer responsibility legislation, we took advantage of our WEEE Directive Series to interview a number of (anonymous) producers (6), treatment providers (8) and legislators (2). These interviews have helped us identify the following issues, summarized in Figure 1.

Setting Targets: To the question "How were the current collection and recycling targets initially set?", the common answer was "lobbying". Before the legislation was enacted, producers lobbied to decrease the targets to avoid the potential future costs. The green organizations lobbied to increase the targets to increase the environmental savings. The treatment providers were teaming up with the green organizations to increase their business. This lobbying process resulted in the current targets of the WEEE Directive. The impact of these rather arbitrary targets is still unclear.

Product Categorization: Intuitively, one would expect that collection and treatment targets be related to the environmental hazard of the products. However, the WEEE targets are only based on the weight of the products. Contrary to the original assumptions, the use of weight-based targets does not assure that producers adapt the design of their products as intended (Mayers et al. 2005).

Individual Producer Responsibility: Currently, manufacturers see no incentive for individual systems. Most manufacturers prefer collective systems to take advantage of scale economies. They have formed collective take-back systems (see (ERP 2007)), where most take-back related activities are delegated to third-party treatment providers. Cost allocation between manufacturers is weight-based and is managed at best by sampling the collected products.

Fairness: The most important problem from the manufacturers' point of view is lack of fairness. They fear the existence of free riders, and look for level playing grounds. Compliance assurance is very important to them.

Collection Assurance: It is not clear in the directive who pays for the cost of assuring a 4 kg per capita collection target. A tendency to shift the cost of collection assurance to the manufacturers has been observed in some countries such as Portugal and Ireland, but it is unknown to which extent this could be managed.

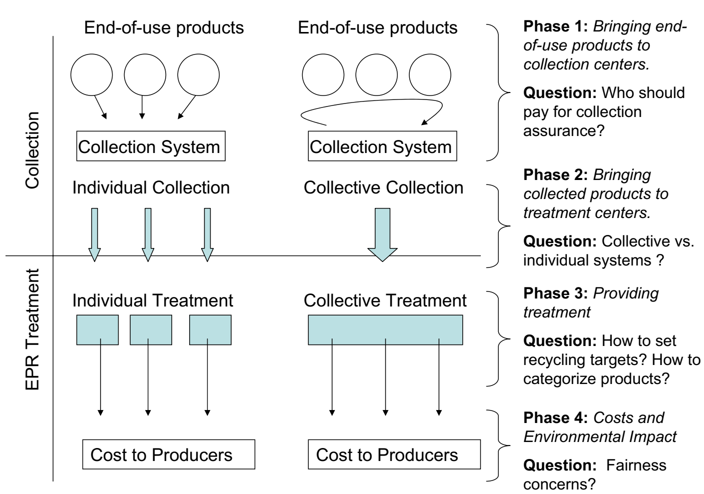


Figure 1: The WEEE Directive at a glance

To date, the WEEE Directive raises more problems than it solves, and it does not seem to cover its stated intentions. Its environmental benefits are limited, and the directive mainly serves for landfill avoidance, to please consumers and green organizations. Because the classification of product categories and selection of targets are not related to any environmental impact measure but weight, most producers state that they do not have an incentive to increase the environmental friendliness of their products, and therefore they do not invest in environmental designs. The WEEE Directive also creates fairness concerns and it is perceived as a hidden tax by producers. The cost of take-back is estimated to be around 2% of revenues, which is enormous given the small profit margins of many electrical and electronics products. Needs for improvement are evident, and one needs to better understand under what conditions it makes sense to enact such legislation.

As such, our purpose in this paper is to provide a framework for thinking about the environmental and economic impacts of such legislation, and all related issues of implementing it. Using a stylized economic model of a take-back system, we discuss improvements to the existing implementations from a market-based legislative perspective. In section 2, we develop our economic model to account for the economic and environmental impacts of the take-back legislation. In section 3, we analyze our model. We first discuss a target setting mechanism that balances the costs and environmental benefits of taking back used products. Then, we discuss the competitive implications of such legislation. We show that the legislation should consider the competition intensity in the market to decide on the take-back targets. Next, we argue that the fairness concerns of the manufacturers can be solved by enforcing individual producer responsibility. We then consider the cost of collection assurance, i.e., consumer education. We also discuss the possibility of rewarding manufacturers for implementing take-back systems, and show that take-back subsidies can only be optimal for taking back very hazardous products. Finally, in section 4, we extend our main model to discuss the impact of alternative cost structures on the efficiency of the target setting mechanism identified before. In section 5, we summarize the results of our stylized models and conclude with our suggestions for designing efficient WEEE-type take-back systems .

2 Model

In this section, we formulate our generic model of a stylized market for a single product category, considering the current form of the WEEE legislation with collection and recycling targets. There are three types of decision makers: Consumers, manufacturers and a social planner (government).

The sequence of events is as follows: First, the social planner sets a target collection rate (c) and a target recycling rate (r). This formulation assumes that the collection target is defined as a fraction of what has been sold (Unlike WEEE, where the collection target is 4kg). Given the collection and recycling targets, the manufacturers set the sales quantity (q) given the costs of collection, recycling and manufacturing for the specific product of interest. Then, given the prices/quantities the consumers buy the product.

Consumers: Consumers are differentiated in terms of their willingness to pay (θ) for the specific product of interest. For the sake of analytical tractability, we assume that consumer willingness to pay for the product is uniformly distributed between 0 and 1, and the market density is normalized to 1. Given the price of the product p, a consumer with willingness to pay θ' buys the product if $\theta' \geq p$. This results in a simple Cournot inverse demand function, i.e., $p = 1 - q$, where q is the total quantity sold.

Manufacturers: We consider n identical manufacturers in the market. Manufacturers play a Cournot game to obtain their market shares. They choose sales quantities to maximize their profits. Price is driven by the total quantity sold by n players in Cournot competition, i.e., $p = 1 - \sum_{i=1}^{n} q_i$, where q_i is the amount sold by firm i ($i = 1 \cdots n$). The manufacturer quantity decisions depend on the market structure as well as on costs involved. Each unit costs μ to produce. $\phi(r, c)$ is the cost per unit of product sold, of taking back a fraction c ($0 \leq c \leq 1$) of sold products and recycling a fraction r ($0 \leq r \leq 1$) of products taken back. We assume $\phi(r, c)$ is an increasing convex function of c and r and $\phi(1, 1) < 1 - \mu$, such that the take-back obligation does not drive manufacturers out of the market. A certain proportion of manufacturers' take back cost may be subsidized by the social planner. Denoting the subsidy per recycled product by σ, each manufacturer receives a total of $q_i rc\sigma$. Manufacturer i then maximizes his profits:

$$\Pi_{M_i} = q_i(p - \mu - \phi(r, c) + \sigma rc)$$

where $p = 1 - \sum_{i=1}^{n} q_i$. It is straightforward to show that at equilibrium, manufacturer i chooses

$$q_i^* = \frac{1 - \mu - \phi(r, c) + \sigma rc}{n + 1}, \; p(q_i^*) = 1 - nq_i^* \tag{1}$$

and obtains

$$\Pi_{M_i} = (p(q_i^*) - \mu - \phi(r, c) + \sigma rc)q_i^* \tag{2}$$

Social Planner: By anticipating the manufacturers' and consumers' actions (1), the social planner uses the collection rate c and recycling rate r to maximize total welfare. The total welfare in the economy consists of five main terms:

1. Manufacturer Profit:

$$\Pi_M = \sum_{i=1}^{n} \Pi_{M_i} = n(p(q_i^*) - \mu - \phi(r, c) + \sigma rc)q_i^* \tag{3}$$

2. Consumer Surplus:

$$\Pi_C = (1 - p(q_i^*))q_i^* n/2 \tag{4}$$

3. Environmental Benefits: We assume that the environmental hazard is perceived at a per product basis. The environmental cost of not recycling a product is given by ϵ. This parameter is a critical one in this model set-up and is discussed in detail in section 2.1. Then:

$$\Pi_E = -\epsilon(1 - rc)q_i^* n \tag{5}$$

4. The social planner also needs to assure that the targeted collection rates are made available by the consumers. This requires marketing take-back programs to inform the consumers. When the social planner runs such marketing programs, she incurs an additional cost αc^2 to ensure the collection level c. This cost is chosen as a function of the collection rate, not the total quantity collected, as c can be thought of as the percentage of environmentally educated consumers (See (Savaskan et al. 2004) for a similar operations approach, and (Lilien et al. 1992) and (Fruchter and Kalish 1997) for marketing approaches).

5. Finally, the social planner may choose to reward the manufacturers for recycling by providing take-back subsidies. In this case, the social planner's cost of subsidizing is given by $\Omega(r, c, \sigma) = n\, q_i\, r\, c\, \sigma$

The problem to be solved by the social planner is maximizing the total welfare (W) in the system in steady state:

$$\max_{r,\, c,\, \sigma} \; W = \Pi_M + \Pi_C + \Pi_E - \alpha c^2 - \Omega(r, c, \sigma) \tag{6}$$

$$s.t. \quad 0 \le r \le 1 \tag{7}$$

$$0 \le c \le 1 \tag{8}$$

This formulation has three underlying additional assumptions: (i) free disposal of non-recycled products (ii) linear additivity in total welfare, and (iii) integrated manufacturer and treatment provider. We discuss the implications of these assumptions in section 6.2 in Appendix.

2.1 Cost to the Environment (ϵ)

The cost to the environment ϵ is a critical parameter in our model set-up. Naturally, this cost should be related to the physical and environmental aspects of the product of interest, i.e., the physical damage inflicted on the environment. Thus, it is important to measure the environmental impact of manufacturing and not recycling a product. Life Cycle Assessment (LCA) techniques are popular for this purpose in the field of environmental economics. For a detailed review of this literature, we refer to (Mayers et al. 2005) and (Huisman et al. 2003). This literature suggests that the environmental impact of the product is related to the weight of the "hazardous waste" it contains. Taking this into account, we define the ϵ parameter such that it is a measure of environmental hazard which differs depending on the environmental impact of the product. Such a measure ϵ would take into account several issues. For instance, the value of ϵ would depend on the recycling technology used. One form of recycling can be more environmentally friendly than the others. It would also depend on the hazardous material content and the product's physical properties such as volume or weight. This parameter would also reflect the differences of sales volumes between products. For products that are sold at a larger scale and that have higher environmental impact, this value would be higher. While a detailed analysis of these issues is beyond the scope of this paper, we refer the reader to Huisman et al. (2007), who provide a highly detailed analysis of these issues specifically in the European WEEE context.

For our purposes we need to find a way of comparing the ecological impact with the economic surplus change. Environmental economists usually plot these two on two-dimensional graphs where they correlate the environmental costs with the environmental savings obtained ((Bovenberg and Goulde 1996), (Mayers et al. 2005), (Ruedenauer et al. 2005), (Kalimo 2006)). Unlike this classical approach, measuring the cost to the environment in monetary terms is an important requirement for our model. In principle, determining the economic value of this parameter needs scientific investigation that takes into account various long term sustainability goals. Recent work on measuring the economic impact on global warming is one example of such an approach. For instance, Sir Nicholas Stern (Stern 2006) concludes that a yearly investment of one percent of global gross domestic product (GDP) is required to avoid the worst impact of climate change, while the failure to do so could decrease the global GDP by 20 per cent. A comparison between the potential environmental cost of landfill and certain recycling technologies can be made in a similar way. Another possible approach could be interpreting the ϵ parameter as the market's perception of environmental hazard. By looking at the public willingness-to-pay for avoiding the harm to the environment, one could find another economic measure to quantify ϵ. This is still hard to measure: Some could argue that this approach is fundamentally wrong since the consumers would never care enough for the environment while the authors of this paper are more optimistic. The environmental economics literature is very helpful in this sense as it suggests ways of measuring the willingness-to-pay. For instance (Hazilla and Kopp 1990) have been able to estimate the social cost of implementing environmental quality regulations and (Smith and Huang 1995) estimate the consumer willingness-to-pay for a marginal increase in the air quality.

Estimating or quantifying this parameter is beyond the scope of our analysis, since our purpose is to generate insights using stylized models. For the remainder of our analysis we assume that this kind of measure exists with the economic interpretation.

3 Analysis

3.1 Base Model

Let us first consider a simple monopolistic scenario ($n = 1$) where market information is costless ($\alpha = 0$) and no subsidies are allowed ($\sigma = 0$), to focus on the selection of collection and recycling targets at optimality. We consider the case where collection and recycling costs are linear in the collection and recycling rates, i.e. $\phi(r, c) = \chi c + \rho rc$, as most practical data provides average treatment and collection costs (see Table 8 in Appendix for examples from (Chen et al. 2004)). We will discuss the relaxation of this linear cost assumption later.

Proposition 1 *The social planner's optimal decision under the base model is summarized in Table 2. The recycling target (as a percentage of the collected returns) r should always be selected at its upper bound ($r = 1$) for $c > 0$. The optimal collection rate is decreasing in the collection and recycling costs (χ and ρ), and increasing in the cost to the environment (ϵ).*

Proof. All proofs are provided in the Technical Appendix at (Atasu 2007). ■

The solution to the social planner's problem is summarized in Proposition 1. A positive collection rate is optimal only when the environmental cost is sufficiently high. It turns out that for all $c^* > 0$, the optimal recycling rate is $r^* = 1$. This is intuitive, because collection is costly and the cost of recycling a product can always be avoided by not collecting that product. This result is obviously driven by the fact that we assume a linear cost structure and perfect recovery is possible. In practice however, there may be upper bounds on the recovery levels, i.e., it may not be technically feasible to recycle everything. Nevertheless, the intuition of the above result suggests that the recycling rate be selected at its upper bound when the costs are linear. The situation may be different when the cost of recycling is increasing in the recycling percentage. In this case, the optimal solution changes. We consider this issue in section 4.1.

Table 2: Optimal solutions for social planner given the possible parameter realizations

	$\epsilon \leq \frac{3(1-\mu)}{2}\left(\frac{\chi+\rho}{1-\mu+\chi+\rho}\right)$	$\frac{3(1-\mu)}{2}\left(\frac{\chi+\rho}{1-\mu+\chi+\rho}\right) \leq \epsilon \leq \frac{3(\chi+\rho)}{2}$	$\epsilon \geq \frac{3(\chi+\rho)}{2}$
c^*	0	$c = \frac{1}{2}\left(\frac{1-\mu}{\chi+\rho} + \frac{3(1-\mu)-4\,\epsilon}{3\,(\chi+\rho)-4\,\epsilon}\right)$	1
r^*	any $r \in [0,1]$	1	1

As one reason for enacting take-back directives is creating incentives for the manufacturers for eco-efficient designs, one would expect that the monopolist would invest in economical collection and recycling systems, or even change the design of the product such that it would be cheaper to collect and recycle and less harmful to the environment. Recall that our model assumes an explicit consideration of environmental impact in the formulation. Let us now investigate whether the directive achieves its targets with this consideration. According to Proposition 1, the higher the cost to the environment (or the consumer perception of ϵ), and the lower the collection and recycling costs, the higher the optimal collection rate. In other words, assuring the best welfare outcome requires the legislative targets to be adapted to the changes in the system and if the above-mentioned scenario takes place, increased targets would help improve the total welfare. On the other hand, the monopolist's anticipation of changes in the legislation may result in unexpected outcomes. The monopolist may anticipate that if he reduces the cost of treatment, the government will increase the optimal collection rate. This, in turn may result in the monopolist not investing in reducing the treatment costs by anticipating the social planner's action.

Corollary 1 *The monopolist's profit is decreasing in the cost of treatment* $(\chi+\rho)$ *when* $\epsilon \geq \frac{3(1-\mu)}{4}$*, and increasing otherwise, as long as the optimal collection rate* $c^* \in (0,1)$*.*

When the optimal collection rate is equal to zero ($c^* = 0$), the monopolist is worse off with reduced treatment cost $(\chi + \rho)$ since reducing this may lead to a positive imposed collection rate c. On the other hand, when $c^* = 1$ the monopolist is better off with reduced costs as after $c = 1$ the collection rate can no longer increase. Interestingly, for an interior c, the basic driver of this investment decision is the manufacturing cost μ. When the profit margin of the monopolist is sufficiently high (i.e., μ low) , the manufacturer's profit will be decreasing with lower treatment costs, as the imposed collection rates will be higher. On the other hand, when the monopolist's profit margins are low (i.e., μ high), the decrease in the treatment cost will increase manufacturer profits, even though the imposed collection rate increases.

On the other hand, from Table 2 it is easy to see that the targets are always increasing in ϵ and it is always to the manufacturer's benefit to reduce ϵ, if the legislation sets targets according to the environmental impact ϵ. This suggests that: *A take-back legislation setting collection and recycling targets according to environmental impact may result in improved welfare outcomes by providing economic incentives to the monopolist.* This has important implications for the WEEE Directive where collection and recovery targets are weight-based and categorization is done with respect to industrial segments (e.g., white goods or consumer electronics): (i) Weight based take-back legislation may not necessarily be efficient since weight may not always be a good measure of environmental impact, and (ii) The take-back legislation should consider the environmental impact of each product individually. Product categorization should be done with respect to the environmental impact of products.

3.2 Competition

In this section, we extend our base model to an oligopolistic setting to account for the impact of competition on: (i) the target setting mechanism, and (ii) the environmental and economic efficiency of take-back legislation. There are n firms in the market, information is again costless ($\alpha = 0$), and no subsidies are allowed ($\sigma = 0$). Considering the result from Proposition 1, due to the linear cost assumption, we assume all collected items will be recycled ($r^* = 1$). We will use the same notation except that ρ now denotes the sum of collection and recycling costs, i.e., $\phi(r, c) = \rho c$.

Proposition 2 *The optimal decision of the social planner under competition (of n firms) is summarized in Table 3. The optimal collection rate is decreasing in collection and recycling costs (ρ) and increasing in the degree of competition (n) and cost to the environment (ϵ).*

Table 3: Optimal collection rate under competition

	$\epsilon \leq \frac{(1-\mu)\rho}{1-\mu+\rho}\left(\frac{n+2}{n+1}\right)$	$\frac{(1-\mu)\rho}{1-\mu+\rho}\left(\frac{n+2}{n+1}\right) \leq \epsilon \leq \rho\left(\frac{n+2}{n+1}\right)$	$\epsilon \geq \rho\left(\frac{n+2}{n+1}\right)$
c^*	0	$\frac{(-1+\mu)\, n\, (2+n)\, \rho+\epsilon\, n\, (1+n)\, (1-\mu+\rho)}{n\, \rho\, (2\, \epsilon\, (1+n)-(2+n)\, \rho)}$	1

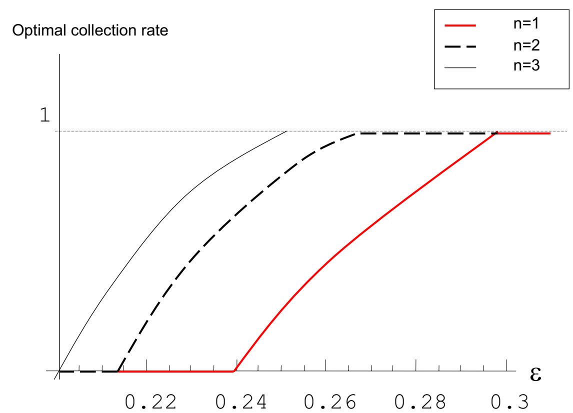


Figure 2: Impact of competition and environmental costs on the optimal collection rate

Proposition 2 points to a strong result: *The optimal collection rate is increasing in the degree of competition (n).* Figure 2 illustrates this result by displaying the impact of competition and environmental hazard on the optimal collection rate. To understand the underlying causes of this result, we need to observe how the elements of welfare change under competition. When the number of competing firms increase, price declines. This leads to lower manufacturer profits and higher consumer surplus. At the same time, due to lower price more consumers buy the product, increasing the output. Thus, while the consumer surplus is increasing, manufacturer profits and the environmental benefits are decreasing in the degree of competition. The last effect is what we call *the environmental externality of competition.*

Figure 3 displays the environmental externality of competition. It illustrates the case of a *static legislation*, where the collection rate is independent of the number of competing firms. The collection target in this figure is set assuming $n = 3$, namely $c \approx 0.2$. Note that the environmental benefits are decreasing with increasing n in Figure 3. Moreover, the total welfare (including producer profit,

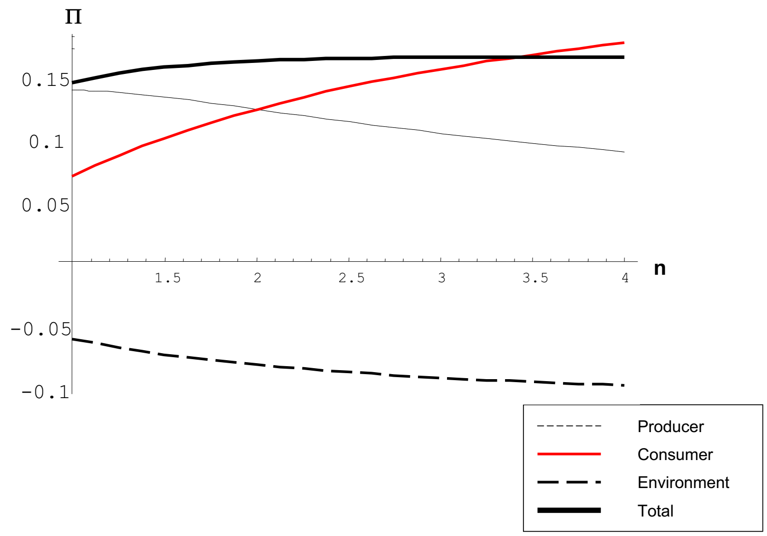


Figure 3: The impact of competition under a static legislation, for $\mu = 0.2$, $\rho = 0.2$, and $\epsilon = 0.24$

consumer surplus and the environmental benefits) is also decreasing with n when $n > 3$. This means that a static take-back legislation that does not account for the degree of competition does not necessarily lead to desired welfare outcomes. As Figure 3 shows, benefits from competition are transferred directly to consumers since the consumer surplus is the only element that increases with competition. The burden is carried by producers and the environment.

The negative environmental impact of competition can be overcome by *dynamic legislation* that sets targets according to the degree of competition. Consider Figure 4, where the take-back legislation is dynamic and the collection rate is adjusted to the competition level according to Proposition 2. In this case, the legislation is efficient, meaning that the total surplus is increasing with n. Moreover, the environmental gains are increasing with the competition level. The message is clear: *Competition can be useful for the environment if legislation is adapted to the industry structure.* It is important to note how this is achieved though. Basically, to obtain the increase in environmental savings the social planner needs to increase the collection rates. This means higher costs to the manufacturers and higher prices for the consumers. This helps the environment in two ways: (i) It reduces the output (ii) it reduces the proportion of output that remains as waste. The producers are the ones who suffer the most from the environmental externality. Comparing Figure 4 to Figure 3, we observe that the manufacturer profits are decreasing faster and the consumer surplus is increasing slower with higher competition under a dynamic legislation.

To summarize, our results suggest punishing the manufacturers more when there is tougher competition. There is also a simple but powerful message to the legislators: Set up the collection levels

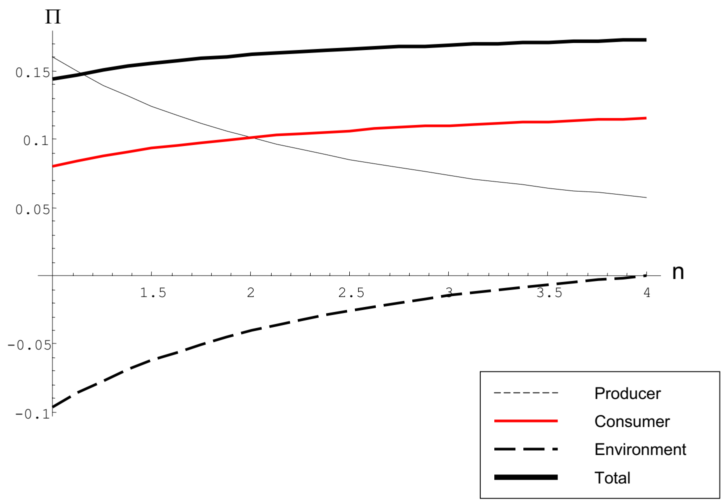


Figure 4: The impact of competition under a dynamic legislation, for $\mu = 0.2$, $\rho = 0.2$, and $\epsilon = 0.24$

according to the industry structure! (Note that this points to another interesting discussion. Increasing collection rates with tougher competition means increasing marginal costs with higher competition. This may also result in creating artificial trade barriers to low margin competitors coming into the region.)

3.3 Fairness

According to Business Week (Woellert 2006), Hewlett Packard Co. has supported the enacting of take-back laws in the US, while Apple Computer Inc. has worked against it. (Woellert 2006) states that HP's efforts are not entirely altruistic. The company's investments in the recycling and reuse business have made take-back a competitive strength for HP. In 2005, HP recycled more than 70,000 tons of products and collected more than 2.5 million units of used products to be refurbished or resold. Thus, HP could see the implementation of take-back laws as a means of creating competitive advantage. On the other hand, Apple has been the greens' disappointment. Although the company's brand image is more environmentally oriented, Apple lags behind HP and Dell in voluntary recycling. However, Apple says critiques ignore the company's efforts to use recyclable and clean materials in its products, i.e., 90% of Apple products can be recycled. The Chief Operations Officer Timothy D. Cook said: "It's important to look at the process as a whole. Not just one part." (Woellert 2006).

So far, our competition model considered identical firms and did not reflect this problem. We assumed with this model that all products from all manufacturers had identical collection and recycling costs as well as environmental impacts, hence there were no free riders. In reality, this is not the case. Firms with lower treatment costs and higher environmental impacts may be given a competitive advantage. The structural improvements for the legislation suggested by our models so far are not sufficient to overcome the fairness issue. Consider the following examples:

Example 1 *Assume that there are two identical firms with* $\mu_1 = \mu_2 = 0.5$*,* $\rho_1 = \rho_2 = 0.2$ *and* $\epsilon_1 = \epsilon_2 = 0.22$*. Using proposition 2, the optimal collection rate can be calculated as* $c^* = 0.596154$ *and the manufacturer profits at this point are realized at* $\Pi_M = 0.0161095$*.*

Example 2 *Now, assume that there are two firms differentiated in their product design for the environment. For the first firm (*M_1*), let* $\mu_1 = 0.5$*,* $\rho_1 = 0.2$ *and* $\epsilon_1 = 0.22$*, and for the second firm (*M_2*),* $\mu_2 = 0.5$*,* $\rho_2 = 0.2$ *and* $\epsilon_2 = 0.24$*. In this case, with a simple numerical analysis the optimal collection rate is found to be* $c^* = 0.715517$ *and the manufacturer profits at this point are realized at* $\Pi_{M_1} = \Pi_{M_2} = 0.0141528$*.*

Example 2 shows that the manufacturer with lower environmental impact is punished for the other manufacturer's environmental hazard even when the targets are intelligently set. The collection target is higher in example 2 due to the fact that the weighted average environmental hazard is higher because of the second manufacturer's product. So the question is, why should a manufacturer increase the environmental quality of his product, if he is going to pay for the free riders?

Example 3 *Now, assume that there are two firms differentiated in their treatment costs. For the first firm (*M_1*), let* $\mu_1 = 0.5$*,* $\rho_1 = 0.2$ *and* $\epsilon_1 = 0.22$ *and, for the second firm (*M_2*),* $\mu_2 = 0.5$*,* $\rho_2 = 0.18$ *and* $\epsilon_2 = 0.22$*. In this case, the optimal collection rate is found to be* $c^* = 0.742058$ *and the manufacturer profits at this point are realized at* $\Pi_{M_1} = 0.0125998$ *and* $\Pi_{M_2} = 0.0161519$*.*

Example 3 shows that the second manufacturer, by reducing the treatment costs can gain a competitive advantage and lower the other manufacturer's profits by 25% while increasing his profits. So, there may be a stronger incentive on reducing the treatment costs rather than increasing the environmental quality of the product. If the government considers an average treatment cost and an average environmental impact for broad product categories and then imposes the targets accordingly, this may not create incentives for the manufacturers to design greener products. Note that this is precisely what the WEEE Directive does!

One manager from a global computer manufacturer made the following statement during our interview at the WEEE Directive Series held at INSEAD (see www.insead.edu/weee): "We would invest in the environmental specs only if we could benefit from those. If I am going to collect some competitor's non-recyclable computers, why should I invest in recyclable computers with better environmental quality?". The important message here is that individual producer responsibility is "the key" to efficient and fair legislation. *The take-back legislation may lead to better environmental outcomes if every single* *manufacturer is responsible for what he produces.* It seems that the better way of implementing such legislation is enforcing more individual producer responsibility. If every manufacturer were responsible for his product's environmental quality and the targets were set up accordingly, the fairness issue could be solved. The current WEEE Directive unfortunately signals important free riding opportunities to high environmental hazard product manufacturers with low recycling costs.

Naturally, the practical feasibility of individual producer responsibility legislation is not obvious. Measuring the environmental quality of each product from each manufacturer, and monitoring all collection and recovery activities is a very difficult task. This is probably the reason why the legislators have not chosen this alternative. Nevertheless, the parties that could benefit from individual responsibility would be willing to invest in systems to assure individual producer responsibility. In our context, these players would be the firms that suffer from fairness issues, and the green organizations. Recalling the Business Week example (Woellert 2006) on computer take-back, there is a message to the green manufacturer: Lobbying for the inclusion of environmental impact into the take-back legislation can be wiser than fighting against the legislation.

3.4 Consumer Education and Marketing

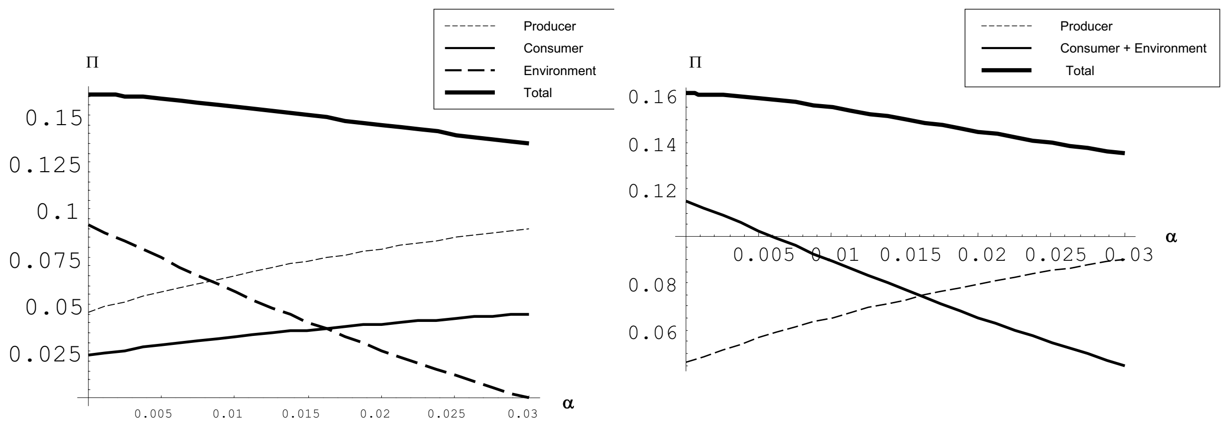
Culture plays an important role in the efficiency of take-back legislation. If the end-users do not return products, reaching collection targets may not be feasible. Practical evidence from European Countries supports this argument since collection rates are significantly different. (Kim 2002) shows that this is the case under the European End-of-Life Vehicle Directive. While very high collection rates (estimated around 99 %) have been achieved in Sweden, the collection rates in the UK are significantly lower (estimated around 50 %). (Boelen 2006) points to a similar result in household waste collection in Europe. While the household waste processing percentage in Sweden is 86%, this rate goes down to 26% in the UK. Therefore, achieving collection targets not only requires collection systems but also end-user consciousness. So far we assumed that the level of collection could be chosen by the social planner without incurring any cost. Higher collection rates may require additional effort (i.e., for B2C types of products this would mean educating consumers, advertising, etc.) in different societies.

In this section, we extend our competition model to account for the social planner's cost of consumer education α. The social planner incurs αc^2 additional cost to ensure the collection level c.

Proposition 3 *The optimal decision of the educating social planner under competition (of n firms) can be summarized as in the Table 4. The optimal collection rate is decreasing in collection and recycling costs (ρ) and cost of education (α), and increasing in the degree of competition (n) and cost to the environment (ϵ).*

Table 4: Optimal solutions for educating planner given the possible parameter realizations

	$\epsilon \leq \frac{(1-\mu)\rho}{1-\mu+\rho}\left(\frac{n+2}{n+1}\right)$	$\frac{(1-\mu)\rho}{1-\mu+\rho}\left(\frac{n+2}{n+1}\right) \leq \epsilon \leq \rho\left(\frac{n+2}{n+1}\right) + \frac{2\alpha}{1-\mu-\rho}\left(\frac{n+1}{n}\right)$	$\epsilon \geq \rho\left(\frac{n+2}{n+1}\right) + \frac{2\alpha}{1-\mu-\rho}\left(\frac{n+1}{n}\right)$
c^*	0	$\frac{(-1+\mu)\,n\,(2+n)\,\rho+\epsilon\,n\,(1+n)\,(1-\mu+\rho)}{2\,\alpha\,(1+n)^2+n\,\rho\,(2\,\epsilon\,(1+n)-(2+n)\,\rho)}$	1



(a) Reflection of cost of education on the manufacturer profit, consumer surplus and environmental savings (at the optimal collection rate)

(b) Reflection of cost of education on the manufacturer profit, and consumer surplus when the consumer bears the environmental costs (at the optimal collection rate)

Figure 5: Collection Impact for $n = 1$, $\mu = 0.2$, $\rho = 0.2$ and $r = 1$

Proposition 3 states that the optimal collection rate is decreasing in the cost of education, which is quite intuitive. Figure 5 on the other hand, points to an interesting question: Who carries the burden for the cost of education ?

Consider Figure 5a first. In this figure, the cost of education is neither reflected on manufacturers, nor on consumers. In this case, the environmental benefits are decreasing in the cost of education and the cost of education is carried solely by the environment. Both manufacturer profit and consumer surplus are increasing in the cost of education because the higher the cost of education, the lower the collection rate. This results in lower manufacturer costs and thus prices for the products. Lower costs and prices increase manufacturer profits and consumer surplus. In this case, both manufacturers and consumers are better off with consumers that are harder to educate. Educating consumers is not beneficial to these players, which seems to resemble an ostrich's policy. When the end-users do not care about the environment, it is the environment that suffers. The current situation in the US may be an example of such cases since no active consumer education policy is observed.

Figure 5b shows how the situation changes when the consumer behavior is altered. When the consumers consider the environmental burden as a cost to their budget, the situation is different. In this case the consumer welfare can be represented as the sum of economic consumer surplus and the environmental savings. In Figure 5b, this sum is decreasing in the cost of education, which means that when the consumers are willing to protect the environment, they are better off with lower education costs. In other words, education is better for environmentally conscious consumers.

The social planner needs to create a budget ($B = \alpha c^2$) for consumer education. The first option that comes to mind is charging the manufacturers for the cost of education, which is the case for countries such as Portugal and Ireland. Assume that the manufacturers are held responsible for a part of the cost of education (i.e. $\alpha' = \beta\alpha \; |\beta < 1$). In this case, given the optimal collection rate c, the manufacturers' decisions are indirectly affected by the cost of education via the change in the collection rate. The condition for keeping an efficient market is that $\Pi_M - B \geq 0$. Note that both Π_M and the cost of education are decreasing in c. Therefore, a sufficient condition for efficient taxation can be obtained at $c = 1$, that is when $\alpha' \leq \frac{n(1-\mu-\rho)^2}{(1+n)^2}$. Figure 5 shows an example where this holds. One mechanism for this policy would be charging the manufacturers their part of cost of education at certain points in time, considering their sales. Let $\kappa = \alpha' c/q$ and assume that the manufacturer is charged κ per product sold, at such a time point (e.g., every year). In this case, a manufacturer's (say i) decision problem can be written as: $\Pi_{M_i} = pq_i - \mu q_i - (\rho + \kappa)cq_i$. Note that manufacturer's quantity decision is independent of α' and this policy is implementable at the optimal collection rates of proposition 3, given the sufficient condition above holds.

It is worthwhile to note that these costs may not be the same for public and private parties. The cost of implementing such programs may change depending on the undertaker and the cost allocation should depend highly on the undertaker of these activities. Another interesting discussion here is on the allocation of the cost of education α' to the manufacturers. It is known that countries such as Portugal and Ireland are forcing the manufacturers to pay for consumer education but we do not know much about the efficiency of this approach. According to our education model, the upper bound on α' is decreasing in the intensity of competition n. This would suggest that for higher degrees of competition, the education budget should be increasingly carried by the consumer side. Taxing the consumers may be a better alternative for markets with higher degrees of competition. We should, nevertheless, interpret these findings within the boundaries of our stylized models. This discussion ignores several issues such as how education costs can be passed through from manufacturers to consumers, the effectiveness of education as a function of who teaches and how education costs depend on the undertaker.

3.5 Subsidized Take-Back

In the US, take-back is made mandatory for some industries, while for some others a competitive advantage is offered to companies who consider take-back seriously (Lion Tech. 2006). Under EPA's performance track program, over 400 companies get special reduced regulation as well as the enhanced public relations (EPA 2006). We asked the WEEE Directive Series participants for their opinions about governmental subsidies. Interestingly, most manufacturers suggested that subsidies would not be useful, since they would bring additional fairness concerns and they would even complicate the implementation of the directive. The legislators stated that it would be extremely hard to monitor and that they did not feel like they needed to provide subsidies anyway.

This section contains the social planner's choice of subsidizing companies for recycling. We extend our competition model by allowing the social planner to choose a per recycled product subsidy σ. Recall that higher collection rates increase prices and result in lower manufacturer profits and consumer surplus. The purpose of a subsidy is to reduce this negative economic impact of the collection cost on the manufacturers and consumers. The main question we want to answer is: "When would a subsidy result in an improved welfare outcome?"

Proposition 4 *The social planner uses subsidies only under perfect collection ($c^* = 1$) with $\sigma = \frac{1-\mu-\rho}{n}$. A sufficient condition for the optimality of a subsidizing solution is $\epsilon \geq \rho$. When the optimal collection rate is below 1, subsidies are not optimal, and the optimal policy is determined by proposition 2.*

Proposition 4 states an important result: *Subsidies are optimal only under perfect collection and high environmental hazard.* Recall that the social planner pays subsidies to reduce the impact of collection cost. This reduction in collection cost results in lower sales prices and increases the total output. Meanwhile, subsidies increase the environmental hazard due to increased output, unless a high collection rate is imposed. Therefore, the social planner needs to trade off the increase in environmental hazard against the increase in manufacturer profits and consumer surplus, if she wants to pay subsidies. Proposition 4 shows how the social planner can balance the two. The social planner chooses to pay subsidies only when the environmental burden is high ($\epsilon \geq \rho$) and she enforces perfect collection. At perfect collection, whatever the sales quantity, the environmental hazard is minimized.

Now assume that the environmental hazard is sufficiently high (i.e., $\epsilon \geq \rho$), and observe what happens with the legislation. Proposition 4 states that in this case $\sigma = \frac{1-\mu-\rho}{n}$, and perfect collection ($c^* = 1$) is optimal. The optimal sales quantity $q^* = \frac{1-\mu+\frac{1-\mu-\rho}{n}-\rho}{1+n} = \frac{1-\mu-\rho}{n}$, and the optimal price $p^* = \mu + \rho$. This quantity-price pair gives us the perfect competition outcome. In other words, the legislation makes sure that at optimality the perfect competition outcome is obtained. At this solution, the consumer surplus is maximized at $\Pi^C = \frac{(1-\mu-\rho)^2}{2}$ (as the situation is perfect competition), the environmental damage is minimized ($\Pi_E = 0$), and the total manufacturer profit is $\Pi_M = \frac{(1-\mu-\rho)^2}{n} > 0$.

Similarly to the previous section, an important problem is creating a budget for the subsidy. The government needs to create a budget of size $\Omega(c^*, \sigma^*) = \sigma^* c q^* n = \frac{(1-\mu-\rho)^2}{n} \leq \Pi^C,\ \forall n > 1$. Thus, this policy is implementable if the budget is created from consumers.

Even though we assumed a perfect setting in our model, where there are no fairness concerns, subsidizing did not turn out to be an effective strategy. Our stylized model suggests that subsidizing is not always optimal because of the increased environmental burden due to increased output. Especially when the treatment costs are sufficiently high (i.e. $\rho > \epsilon$) and perfect recovery is expensive, the social planner does not subsidize. Without a subsidy, the social planner chooses an imperfect collection policy to protect the manufacturers and consumers.

4 Extension: The Impact of Cost Structure

It is important to understand the impact of the take-back cost structure because different cost structures are observed in practice. Our interviews with European Electrical and Electronic Equipment manufacturers and treatment providers have suggested two types of cost structures: (i) treatment costs linear in the rates, and (ii) treatment costs increasing in the rates. Furthermore, sometimes recycling can be profitable and manufacturers may be better off with take-back. Examples of such cases include cell phones and products with high steel volume, where material recovery can compensate for the costs of collection and recycling.

We have discussed the costly take-back situation under linear treatment costs in the previous section. In this section, we consider the impact of non-linear costs and profitable take-back. We first consider the impact of non-linear recycling costs. Then, we look at the impact of non-linear collection costs. Finally, we consider the case of profitable take-back.

4.1 Non-Linear Recycling Costs

The manufacturers we interviewed suggested that recycling costs can sometimes be increasing in the recycling rate. This is usually the case when higher recycling rates require more advanced and costlier recycling technologies. To take this into account, we change our treatment cost structure to $\phi(r, c) = \chi c + \rho r^2 c$, i.e., the recycling cost increases quadratically in the recycling rate.

Recall that under the linear cost assumption, the recycling rate had to be selected at its upper bound. This logic is no longer true if the marginal cost of recycling is increasing in the recycling rate.

Proposition 5 *Assume increasing marginal recycling costs with $\phi(r, c) = \chi c + \rho r^2 c$. When the optimal collection rate $c^* \in (0, 1)$, the upper bound on the optimal recycling rate is given as $\bar{r}^* = \sqrt{\frac{\chi}{\rho}}$ when $\chi \leq \rho$*

and $\bar{r}^* = 1$ *otherwise.*

Proposition 5 states that the linear case logic no longer applies. There exists an economic upper bound on the optimal recycling rate to be imposed by the social planner that is given by $\bar{r}^* = \sqrt{\frac{\chi}{\rho}}$. Note that when χ is higher than ρ, the optimal recycling rate is set at 1, which is the natural upper bound. On the other hand, when χ is lower than ρ, only a certain proportion of collected items will be recycled.

This result can be explained when $\bar{r}^*$ is replaced in the manufacturer's treatment cost $\phi(r, c)$. At $\bar{r}^* = \sqrt{\frac{\chi}{\rho}}$, $\rho r^2 cq = \chi cq$. This leads to the interpretation that the optimal recycling rate should be chosen at the point where the marginal cost of recycling is equal to the marginal cost of collection. We call $\bar{r}^* = \sqrt{\frac{\chi}{\rho}}$ the *economically efficient recycling rate*. (For similar economic bounds see (Geyer et al. 2007).) It is interesting to note that the economically efficient recycling rate is independent of the cost to the environment ϵ. The only thing that drives the recycling rate is the relation between marginal collection and recycling costs. However, the optimal collection rate c in the interior region, as given below, does depend on ϵ:

$$c^* = \begin{cases} 0 & when \quad \epsilon \leq \frac{3\left(-\left(\sqrt{\chi}\sqrt{\rho}\right)+\sqrt{\chi}\,\mu\sqrt{\rho}\right)}{-1+\mu-2\sqrt{\chi}\sqrt{\rho}} \\ \frac{\epsilon(-1+\mu)+\sqrt{\chi}(3-2\epsilon-3\mu)\sqrt{\rho}}{-4\chi\epsilon+6\chi^{\frac{3}{2}}\sqrt{\rho}} & when \quad \frac{3\left(-\left(\sqrt{\chi}\sqrt{\rho}\right)+\sqrt{\chi}\,\mu\sqrt{\rho}\right)}{-1+\mu-2\sqrt{\chi}\sqrt{\rho}} \leq \epsilon \leq \frac{3\left(-\left(\sqrt{\chi}\sqrt{\rho}\right)+2\chi^{\frac{3}{2}}\sqrt{\rho}+\sqrt{\chi}\,\mu\sqrt{\rho}\right)}{-1+4\chi+\mu-2\sqrt{\chi}\sqrt{\rho}} \\ 1 & o/w \end{cases} \tag{9}$$

Increasing the environmental hazard measure ϵ does not affect the optimal recycling rate but increases the optimal collection rate up to perfect collection, i.e., $c = 1$. In other words, when ϵ is sufficiently low, the social planner uses the collection rate as the main driver of the legislation and sets the recycling rate at the economically efficient level defined above. On the other hand, once the environmental hazard measure ϵ is sufficiently high to require perfect collection, the environmental concerns outweigh the economic concerns, and the optimal recycling rate increases in ϵ. The imposed recycling target exceeds the economically efficient recycling rate as the following example shows:

Example 4 *Assume that* $\mu = 0.2$, $\chi = 0.05$ *and* $\rho = 0.1$. *Then using equation 9, for* $\epsilon > 0.200281$, *the optimal collection rate is* $c = 1$. *Figure 6 shows that the optimal recycling rate is increasing in the cost to the environment when* ϵ *exceeds this threshold for perfect collection.*

4.2 Nonlinear Collection Costs

Similar to the recycling cost, the linear collection cost assumption can be questioned, depending on the way returns are collected. Manufacturers may have to collect the used products in one of two ways: from public collection centers or directly from consumers. When the returns are collected from public

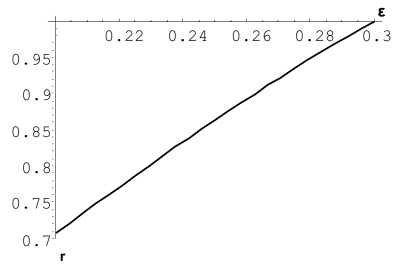


Figure 6: Optimal recycling rate at perfect collection

centers, the linear collection cost assumption would be suitable for the manufacturers. On the other hand, when the manufacturers have to collect from individuals, this assumption may not be reasonable. The cost of reaching additional individuals may increase as the collection rate increases (see Savaskan et al. (2004), for instance). The answers we obtained from our interviews also suggested this. While a significant proportion of manufacturers and treatment providers noted linear costs in the collection rate, others did suggest increasing collection costs.

To model the increasing marginal collection cost, we slightly change our treatment cost structure and assume that $\phi(r, c) = \chi c^2 + \rho rc$.

Proposition 6 *Assume increasing marginal collection cost with* $\phi(r, c) = \chi c^2 + \rho rc$. *The recycling target (as a percentage of the collected returns)* r *should always be selected at its upper bound* ($r = 1$) *for* $c > 0$.

Proposition 6 states that under the increasing marginal collection cost assumption with $\phi(r, c) = \chi c^2 + \rho rc$, the policy from the linear cost model applies. In other words, when the marginal collection cost is quadratically increasing in the collection rate, the recycling rate should still be selected at its upper bound and the collection rate should be selected depending on the cost parameters. Unfortunately, with this assumption, the optimal collection rate cannot be obtained in simple closed form. Nevertheless, the optimal collection rate can be calculated numerically for any parameter setting, and the behavior of the optimal collection rate is similar to its behavior under the linear cost assumption.

The investigation of non-linear collection and recycling costs extend the interpretation of our results from the base model with linear cost assumptions. Our results suggest that at the optimal welfare outcome, one of the two instruments (collection rate or recovery rate) is always at its upper bound. The upper bound on the collection rate is a physical one, i.e., one cannot collect more than what is available. The efficient recycling rate on the other hand has an economic upper bound when the environmental hazard of the product is low, and one needs to compare the *marginal* costs of recycling and collection to determine this bound. We expect that these findings hold for other forms increasing marginal cost functions, but this level of generalization is beyond our scope.

4.3 Profitable Recycling

Several examples from industry show that firms can make a profit by recycling or reusing product returns ((Geyer et al. 2007), (Krikke and Zuidwijk 2006)). For certain industries and product categories these options can be quite attractive. Therefore, it is important to consider the cases where recovery of used products is beneficial to the manufacturer.

To consider the profitable take-back cases, we change our base model slightly. The consumer part of the model remains the same, i.e., $p = 1 - q$. We consider a monopolist, who has the option to collect and recycle used products for profitable material recovery.

Manufacturer: Similar to the base model, it costs μ to produce a unit to the monopolist. The net benefit of recycling (revenue from recycling minus cost of recycling) a used product is denoted by ρ. Collecting recyclable products is costly and collection cost depends on the collection rate. When the monopolist chooses a collection rate of γ, it costs $\chi\gamma^2$ to collect each product. The reason for this assumption is that when the manufacturer is willing to beat the natural supply/demand side limitations, he has to put effort (e.g., collect faster to catch the market, invest in better recovery technology, go to consumers for collection). Furthermore, this was the suggestion of a significant proportion of the manufacturers and service providers we interviewed. We skip the linear collection cost case which is trivial as it leads to a binary solution depending on the sign of $\rho - \chi$.

Note that in this case, the monopolist's collection decision is not the same as the social planner's imposed collection rate c. The monopolist's γ can be larger than the imposed target c. Under these assumptions, the take-back cost is written as $\phi(\gamma) = \chi\gamma^2 - \rho\gamma$.

The manufacturer's objective is:

$$\max_{q,\gamma} \ \Pi_M = q(p - \mu + \rho\gamma - \chi\gamma^2)$$
$$s.t. \quad c \leq \gamma \leq 1$$

Assuming the manufacturer has positive margins ($1 - \mu - \chi > 0$) and recovery is profitable ($\rho > \chi$), the manufacturer's optimal decisions given the imposed recovery target c are summarized in the following lemma:

Lemma 1 *When* $c \leq \rho/2\chi \leq 1$, $q^* = \frac{\rho^2 + 4\chi(1-\mu)}{8\chi}$ *and* $\gamma^* = \rho/2\chi$. *However, when* $\rho/2\chi \leq c \leq 1$, $q^* = \frac{1-\mu+c(\rho - c\chi)}{2}$ *and* $\gamma^* = c$. *Otherwise,* $\gamma = 1$ *and* $q^* = \frac{1-\mu+\rho-\chi}{2}$.

Social Planner: Lemma 1 shows that when the imposed collection rate c is less than $\rho/2\chi$, the collection rate chosen by the manufacturer will be higher than the imposed target. Therefore, we focus on the relevant case and develop the social planner's problem below. In this formulation we assume that the cost of consumer education α is endogenized in χ and the social planner does not provide subsidies ($\sigma = 0$).

$$\max_{c} \; W = \Pi_M + \Pi_C + \Pi_E$$
$$s.t. \quad \rho/2\chi \leq c \leq 1$$

where $\Pi_C = (1 - p(q^*))q^*/2$ and the environmental savings $\Pi_E = -\epsilon(1 - c)q^*$.

Proposition 7 *Assume $\rho \leq 2\chi$. Then the imposed recovery target is $c^* = \rho/2\chi > 0$ even at $\epsilon = 0$. Moreover, c^* is monotonically increasing in the cost to the environment ϵ. When $\rho > 2\chi$, $c^* = 1$.*

Proposition 7 states that the intuition under the benefit model is similar to that of the cost models, i.e., higher recovery targets are required for higher environmental hazard and lower recovery costs (i.e., low χ). Nevertheless, there is an important difference in the social planner's strategy. When recovery is profitable, the optimal collection rate is positive even at zero environmental hazard, while under costly recovery the optimal rate in this case would be zero. There is an intuitive explanation to that: When recovery is profitable, the unit manufacturing cost to the manufacturer decreases in the recovery rate, increasing the manufacturer profit. This is reflected in the sales price, increasing the consumer surplus. At the same time, the total hazard to the environment is reduced with higher recovery rates. This means that all the elements of the total welfare are improved with profitable recovery.

We finalize this section by noting that we did not consider a competition scenario. Previously, we have considered only market competition for the sales of new products as recovery was costly and manufacturers would not benefit from it. When recovery is beneficial however, manufacturers may have to compete for the acquisition of returned products. We refer the reader to (Atasu et al. 2007), (Ferguson and Toktay 2006) and (Majumder and Groenevelt 2001) for a discussion of how the profitable product returns impact competition.

5 Discussion and Summary of Results

This paper presents a model, an abstraction of a few key elements that can be influential in a take-back legislation context. With our stylized economic model, we consider the impact of take-back legislation on the economy and look at the efficiency of existing policies such as the WEEE directive of the European Commission. We argue that the weight (mass) based directives and the weight-based categorization of products may not necessarily be efficient (neither economically nor ecologically). A better categorization of products and the selection of targets would consider: (i) The treatment cost or the benefit from recycling, (ii) The environmental impact of the product, (iii) The willingness-to-pay of customers for the decrease in the environmental impact, and (iv) The competition intensity of the specific market. (See Huisman et al. (2007), a recent study, financed by the European Commission for similar empirical findings.)

We also argue that although the WEEE legislation was aimed at creating incentives for environmentally friendly designs, the manufacturers have not seen much incentive there. According to our stylized models, it appears that a required adjustment to the WEEE directive is the inclusion of individual producer responsibility, where targets are set with respect to environmental measures. This would provide better incentives for manufacturers to create more environmentally efficient designs considering future product take-back. In a take-back framework, setting targets for an industrial category, e.g., IT Equipment, may result in cost competition instead of creating environmental design incentives. With individual responsibility, the fairness/free-riding concerns of the manufacturers can also be addressed, i.e., whoever creates the least environmental impact gets the most benefit or pays the least. We should also note that we have ignored the impact of economies of scale that can be obtained via collective systems. It is true that collective systems may come with a cost advantage, however, it seems that free rider avoidance is most important from the manufacturer perspective. Thus, the best application of a collective system seems to be where cost allocation is done according to the environmental contribution of manufacturers.

Copying environmental legislation does not seem to be a healthy approach. Even in our stylized setting, the targets need to be adjusted to the cost, environmental impact and to the competition level differences in the industry. This means that copying existing WEEE-type legislation may not lead to improved welfare outcomes, as different regions of the world may face different cost structures, environmental consciousness levels and competition.

Consumer education is very important for the efficiency of take-back legislation. However, consumer education is costly and consumer consciousness to environmental policies is crucial for the efficiency of take-back legislation. It is known in the European example that some member states are trying to push manufacturers to pay for consumer education. This cost may harm industries working with small profit margins and it is not clear to which extent manufacturers should be responsible for consumer education. An education policy that is optimal in one state may not be optimal in another, unless the market structure and consumer preferences are in line. Thus, further research taking into account real life complexities of consumer education and identifying cost allocation of consumer education on manufacturers and consumers is essential.

Governments may also consider the possibility of rewarding manufacturers for recycling, but it is important to know when this would help improve total welfare in the system. According to our models, subsidizing is not optimal unless the environmental hazard of the product is very high and perfect collection is optimal. Otherwise, subsidies may increase the total output and hence the environmental impact. This suggests that subsidies may be more meaningful for products that are environmentally hazardous and costly to recycle, e.g., batteries.

Another issue to be mentioned is that the target setting approach in the European Directive need not be the only way of designing legislation. Unlike the WEEE Directive, there is no collection target in the Japanese take back legislation for white goods (Japan 2005). In Japan, consumers are responsible for returning products to collection facilities and pay for recycling related costs. The Californian Directive on the other hand charges consumers a fixed fee at the moment of sales. Although our models can easily be adapted to these different models, the undertaker of the treatment can be different under different forms of legislation, as well as the incentives and the transaction costs involved. The performance of different forms of legislation is a promising research subject.

There are several other future research directions in this context. We did not specify the undertaker of the take-back activity. In our models, the undertaker of any take-back activity, e.g., collection, recovery or even consumer education, incurs the same cost. In practice however, these costs may differ depending on the undertaker. The cost differences between public and private parties can also drive the efficiency of such systems.

Next, academia has to compare the environmental impact of reuse and recycling. According to the WEEE Directive, *reuse* is defined as any operation by which WEEE, or components thereof, are used for the same purpose for which they were conceived, including the continued use of the equipment or components thereof which are returned to collection points, distributors, recyclers or manufacturers. From a waste avoidance perspective, reuse seems to be an environmentally favorable option since it keeps used products away from the waste stream, and a used product can be recycled after being reused. However, efficiency of collection systems is important here. If the collected amount is decreased after each reuse cycle and the uncollected products are dumped or land-filled, reuse may not be an environmentally benign option. Interestingly, the WEEE Directive favors recycling over reuse, and this seems to be an important avenue of future research. The impact of legislation on international trade is also an extremely important issue (Kalimo 2006). Research on the impact of take-back legislation on international trade is required to create suggestions for countries that would like to attract foreign investors.

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References

Atasu, A., M. Sarvary, L. N. Van Wassenhove, "Remanufacturing as a Marketing Strategy," *INSEAD Working Paper*, 2007.

Atasu, A., "Technical Appendix: Efficient Take-Back Legislation," *INSEAD Working Paper*, 2007.

Boelen, J., "Waste as A Commodity," CLSC Workshop 2006 Presentation, 2006, Erasmus University, Rotterdam.

Bovenberg, A. L., L. H. Goulder, "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses ," *The American Economic Review*, 1996,Vol. 86, No. 4, pp. 985-1000.

Chen, P., P. Narayan, L. N. Van Wassenhove, H. Ghaziri, "The WEEE Challenge," *INSEAD Case Study*, 2004.

Ekins, P., "Eco-Efficiency," *Journal of Industrial Ecology*, 2005, Vol. 9 No. 4, pp. 12–14.

Environmental Protection Agency, "Performance Track Program," *http://www.epa.gov/performancetrack* , 2006.

Europa-Environment, "Directive 75/442/EEC, Recovery Operations," *http://europa.eu.int/eur-lex/en/consleg/pdf/*, 2005.

Europa-Environment, "Waste," *http://europa.eu.int/comm/environment/waste/index.htm*, 2005.

European Recycling Platform, "European Recycling Platform," *http://http://www.erp-recycling.org*, 2007.

Ferguson, M. E., L. B. Toktay, "The Effect of Competition on Recovery Strategies," *Production and Operations Management*, 2006, 15(3), pp. 351-368.

Fruchter, G. E., S. Kalish, 1997, "Closed-loop advertising strategies in a duopoly," *Management Science*, 43, pp. 54–63.

Geyer, R., L. N. Van Wassenhove, A. Atasu, "The Impact of Limited Component Durability and Finite Life Cycles on Remanufacturing Profit ," *Management Science*, 2007, 53(1), pp. 88-100.

Green-Peace International, "Eliminate Toxic Chemicals: Alternatives to Incineration," *http://www.greenpeace.org/international/campaigns/toxics/incineration/alternatives-to-incineration*, 2005.

Hazilla M., R. J. Kopp, "Social Cost of Environmental Quality Regulations: A General Equilibrium," *Journal of Political Economy*, 1990, Vol. 98, No. 4, pp.853–873.

Huisman J., C.B. Boks, A. L. N. Stevels, "Quotes for environmentally weighted recyclability (QWERTY): Concept of describing product recyclability in terms of environmental value ," *Int. Journal of Production Research*, 2003, Vol. 41 No. 16, pp. 3649–3665 .

Huisman J., F. Magalini, K, Ruediger, C. Maurer, S. Ogilvie, J. Poll, C. Delgado, E. Artim, J. Szlezak, A. L. N. Stevels, "2008 Review of Directive 2002/96 on WEEE-Final Report," United Nations University Report, Study No: 07010401/2006/442493/ETU/G4.

Japanese Ministry of Environment, “Laws and Regulations,” *http://www.env.go.jp/en/lar/*, 2005.

Kalimo H., “E-Cycling: Linking Trade and Environmental Law in the EC and the U.S. ,” *Transnational Publishers*, Ardsley, NY, 2006.

Kim N., “Exploring Determinant Factors for Effective End-of-Life Vehicle Policy ,” *The International Institute for Industrial Environmental Economics Thesis*, Lund, Sweden, 2002.

Krikke H., R. Zuidwijk, “On the Value of Product Data Management in disassembly of consumer electronic products ,” *Tilburg University Working Paper*, 2006.

Lilien, G. L., P. Kotler, K. S. Moorthy, 1992, Marketing Models, Prentice-Hall, Englewood Cliffs, NJ.

Lion Technology, “Am I responsible for my customers waste?,” *http://www.lion.com/Reference_Library/Newsletter/Vol7Issue17.htm*, 2006.

Majumder P., H. Groenevelt, “Competiton in Remanufacturing,” *Production and Operations Management*, 2001, Vol. 10 No. 2, pp. 125–141.

Mayers C. K., C. M. France, S.J. Powell, “Extended Producer Responsibility for Waste Electronics,” *Journal of Industrial Ecology*, 2005, Vol. 9 No. 3, pp. 169–189.

Ruedenauer I.,C. Gensch, R. Griesshammer, D. Bunke, “Integrated Environmental and Economic Assessment of Products and Processes ,” *Journal of Industrial Ecology* , 2005, Vol. 9, No. 4, pp. 105–116.

Savaskan R. C., S. Bhattacharya, L. N. Van Wassenhove, “Closed-Loop Supply Chain Models with Product Remanufacturing,” *Management Science*, 2004, 50(2), pp. 239-252.

Smith V. K.,, J. C. Huang, “Can MArkets Value Air Quality? A Meta Analysis of Hedonic Property Value Models,” *Journal of Political Economy*, 1995, Vol. 103, No. 11, pp. 209–227.

Stern, N., “The Economics of Climate Change,” Cambridge Press, 2006.

Stevels, A., “Experiences with the Take-Back of White and Brown Goods in The Netherlands,” *http://www.factor10.be/Media/Ab_Stevels_2*, 2006.

US State of California, “Air Resources Board Updated Informative Digest,” *http://www.arb.ca.gov/regact/levii01/uid.pdf*, 2005.

US State of New Jersey, “Office of Air Quality Management Low Emission Vehicles Program,” *http://www.nj.gov/dep/aqm/levprop.pdf*, 2005.

Woellert, L., “HP wants your old PCs Back,” *Business Week*, 10/4/2006, pp. 82-83.

Zhao, Z. 2000, “Raising awareness and signaling quality to uninformed consumers: A price-advertising model”, *Marketing Science*, 19, pp. 390396.

Table 5: EU Legislation for Batteries and Accumulators (percentages of total weight)

Collection Level	Recycling Level				
	Lead-Acid Type		Ni-Cd Type		Others
	Lead	Overall	Cd	Overall	
> 160 gr/inhabitant and > 80%	%100	65%	100%	75%	55%

Table 6: EU Legislation for End of Life Vehicles (ELV) (percentages of total weight)

Deadline	Collection Level	Recycling Level	Recovery Level
By 2005	100% of all returned	75%	75%
By 2006	100% of all returned	80%	85%
By 2015	100% of all returned	85%	95%

6 Appendix

6.1 European Legislation

6.2 Discussion of Assumptions

6.2.1 Free Disposal:

Our models assume free disposal. One could also include the disposal cost of non-recycled items in the model, but this cost can be internalized in the current form of it. Assume a per disposed item cost of δ is incurred by the manufacturer. Then the profit per product of the manufacturer can be written as : $\Pi_M/q = p - \mu - \chi c - \rho rc - \delta c(1-r) = p - \mu - (\chi + \delta)c - (\rho - \delta)rc$. Letting $\chi' = \chi + \delta$ and $\rho' = \rho - \delta$, the same formulation can be obtained.

6.2.2 Linear Additivity in Welfare:

Our representation of total welfare requires linear additivity in the measures used. One can assume that the environmental measure Π_E can be adjusted by playing with the ϵ parameter. However, having the Π_M and Π_C have the same impact may not be a reasonable assumption all the time. In real life, trade associations exist and the lobbying power of the manufacturers can have an impact on the targets (Recall the way parameters were set in the WEEE case.) This suggests that there is a coefficient of power in front of Π_M, i.e. $W = \lambda\Pi_M + \Pi_C + \Pi_E$. From an optimization perspective this is equivalent to having a constraint in the objective function such as $\Pi_M \geq \Pi_0$ where λ is equivalent to the dual of

Table 7: EU Legislation for Packaging (percentages of total weight)

Category	Collection Level	Recycling Level	Recovery Level
Glass, Paper and Board	All in the market	60%	60%
Metals	All in the market	50%	50%
Plastic	All in the market	22.5%	22.5%
Wood	All in the market	15%	15%
Overall	All in the market	55% to 80%	60%

Table 8: Collection and recycling costs for different WEEE categories (Euros/kg)

		Recycling			Collection	
Category	Minimum	Maximum	Average	Min.	Max.	Average
Large household appliances	0.20	0.42	0.31	0.07	0.17	0.14
CFC containing appliances	0.61	1.28	0.86	0.15	0.39	0.25
Small household appliance	0.42	0.55	0.52	0.11	0.28	0.18
IT and telecommunications eq.	0.42	0.77	0.59	0.12	0.28	0.17
TV Sets	0.62	0.79	0.69	0.12	0.25	0.19

this constraint. By definition Π_M is bounded between $\bar{\Pi}_M = \frac{(1-\mu)^2}{4}$ and $\underline{\Pi}_M = \frac{(1-\mu-\chi-\rho)^2}{4}$ and it is decreasing in c and r. Thus any Π_0 between $\underline{\Pi_M}$ and $\bar{\Pi}_M$ can be represented as a combination of upper bounds on r and c. This, in turn, is equivalent to having upper bounds on the decision variables and is already in the formulation.

6.2.3 Integrated Manufacturer and Treatment Provider:

The cost to the polluter can be the income of the environmental service company which will decrease the macro-economic cost to the economy as a whole (Ekins 2005). We note that when discussing the economic implications of such policies we have ignored the fact that recycling in itself can be a business opportunity and assumed that the manufacturer handles the recycling operations. In general however, these activities are handled by third party treatment providers. Thus, the economic impact of creating business for the treatment providers also needs to be considered.

Considering this issue, on the other hand, complicates the analysis as it requires inclusion of the treatment provider's costs, and offers few insights. Nevertheless, it is easy to show that the inclusion of the treatment providers' contribution to the social welfare does not add much, but it complicates the analysis. Consider the following simple model for instance. Assume that there exists a treatment provider, who charges the manufacturer χ per product collected and recycled. The treatment provider incurs treatment cost η per product. In this case, the profit of the manufacturer is $\Pi_M = p^*q^*(1-\mu-\chi c)^2 = (1-\mu)^2 - 2(1-\mu)\chi c + \chi^2 c^2$ and the profit of the treatment provider is $\Pi_T = q^* c(\chi-\eta)(1-\mu-\chi c)c(\chi-\eta)/2$. The sum of these two terms can be simplified to $\Pi_M + \Pi_T = (1-\mu)^2 - 2(1-\mu)\eta c + c^2(2\chi\eta - \chi^2)$. Note that the structure of this sum is very similar to the manufacturer profit alone.

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