DEPOSIT-REFUND SYSTEMS

Economic Incentives for the Reduction and Proper Disposal of Hazardous Waste

by
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I. INTRODUCTION

Hazardous wastes such as spent solvents and heavy-metal paint waste are characterized by certain adverse properties which include toxicity, reactivity, corrosivity, and flammability. Improper disposal of hazardous wastes may lead to air pollution, water pollution, or soil contamination which are dangerous for human health and for the ecosystem. These effects are known as externalities if the consequences, or costs, are not considered in the waste-generators' decisions. Due to externality, the social costs, including externality costs, and private costs diverge. Since the Love Canal event[1], hazardous waste disposal (HWD) has drawn national attention. A Roper poll reported that hazardous waste was perceived by the American public as the most important environmental problem (EPA, 1987; cited by Hammitt, 1988). This concern has led to a number of statutes and regulations to control HWD. This paper will examine the potential role of deposit-refund (DR) systems as a possible strategy to control hazardous waste disposal.

Hazardous wastes are generated by a large number and variety of production and consumption processes. Small quantity generators (SQGs), firms that generate less than 1,000 kg of hazardous waste in a calendar month at a given site, are considered to be a major source of illegal disposal accounting for 30-50% of all wastes illegally dumped in the U.S. (Schwartz and Pratt, 1990). The reasons cited for illegal dumping include lack of awareness of regulations, lack of technical expertise, higher costs for proper disposal, and ineffective enforcement due to high monitoring cost (Hammitt, 1988; Deyle, 1989; Schwartz and Pratt,

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[1]. During 1978, in Love Canal, a residential area of Niagara Falls, New York, large quantities of wastes were buried underground. Later a school and an adjacent housing tract were built there, and the wastes began to seep into the basements and playrooms resulting in extensive health damage.

1990). In their study, Schwartz and Pratt found that more than 50 percent of SQGs did not have proper EPA identification, which led to difficulty in monitoring. Moreover, most SQGs lacked sufficient knowledge about the toxicity of their wastes. These factors have resulted in a high rate of improper waste disposal.

Many economists suggest that policies for regulating hazardous wastes can be made more effective by using economic incentives. These policies[2], such as product charges, subsidies, and user charges, have been widely used in many countries. In addition, a deposit-refund system has been proposed to regulate hazardous waste (Opschoor and Vos, 1989; OECD, 1991; Schwartz and Pratt, 1990; Macauley, Bowes,and Palmer, 1992).

In a deposit-refund (DR) system users pay a deposit on potentially polluting products. When pollution is avoided by return of the waste products or their residuals, the deposit is refunded. DR systems have successfully reduced used beverage container littering. In Europe, for example, due to DR systems, it is estimated that 90 percent of recyclable bottles are returned to recycling centers each year. This result has encouraged governments to apply DR systems more widely to control toxic wastes such as used batteries, waste oils, old tires, and empty pesticide containers (Opschoor and Vos, 1989; OECD, 1991). The objective of DR systems is to reduce waste volumes by using less waste-generating product and to dispose of waste properly to prevent the release of toxic substances into the environment. These toxic substances include residues from landfill disposal of mercury-containing batteries, or from the incineration of plastics that generate soil and air pollution.

While the operating principle of DR systems is simple and appealing, several issues are

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[2]. These policies are discussed in section III.3.1. in this paper.

involved in the design of cost-effective systems. These issues include: how to implement a DR system to regulate disposal of a specific hazardous waste product, how to choose efficient levels of deposit and refund, how a DR system changes social welfare, and how a DR system differs from alternative policies.

The objective of this study is to examine deposit-refund (DR) systems as a means to control hazardous waste disposal. In section II, a review of the literature is included to provide a historical and theoretical bases for the proposed model of DR systems. After the literature review, section III develops a simple general framework of deposit-refund system in regulating waste disposal that generates externalities to determine the Pareto-efficient levels of deposit and refund. The framework is also used to examine the behavior of producers who generate wastes and the consequent welfare effects. In section IV, three case studies are used to examine the effectiveness of DR systems, the distribution of benefits and costs, the associated strengths as well as the weaknesses, and other economic implications. Section V combines the theoretical framework and the three case studies to address the issues involved in designing an effective DR system. Finally, conclusions and recommendations for future research are proposed in section VI.

II. REVIEW OF THE LITERATURE

The purpose of the literature review is to examine how DR systems are structured from a theoretical perspective. Only a few articles provide a theoretical justification for deposit-refund (DR) systems. However, the models that these articles proposed are complicated. For an illustrative purpose, this literature review would refer to all of these studies for an insight on how a DR system framework is formulated.

In 1932, Pigou proposed a tax/subsidy scheme to control externalities. A tax was imposed on negative externalities while a subsidy was imposed on positive externalities. If the tax or subsidy rate was equivalent to the marginal external effect, Pareto efficiency was achieved (Pigou, 1932; cited by Baumol and Oates, 1979).

Solow (1971) and Mills (1972) proposed a DR system - whereby a material disposal tax levied on raw materials was combined with refunds when the material was properly disposed. They suggested that the tax rate should equal the estimated damage cost of the most harmful method of disposal, while the refund rate should depend on the disposal method employed. Desirable methods (generation of less externalities), such as recycling, should receive a full refund, while environmentally damaging methods that produced negative external effects should receive only a partial refund. They also recommended that an interest rate might be incorporated in the deposit to prevent erosion of the deposit's real value for a durable product. They argued that such charges would make the prices of materials including disposal reflect social costs, rather than private costs. Due to the different external effects for each input, the original choices of materials would be Pareto optimal. Moreover, the refunds would accurately reflect the social costs of various methods of disposal which would induce firms to choose a method of disposal in light of both the direct costs and the accompanying refund.

The advantage of this DR scheme, Solow concluded, was that controlling upstream producers was easier than controlling downstream users because their number was relatively smaller than the number of those downstream. However, a DR system would have created a burden on policy-makers who would have to monitor the procedure of the return process.

Moreover, Solow, expanding on this approach, proposed that all users of raw materials might be required to provide a bond which could be refunded if firms could avoid any damage by recycling or reuse[3].

Bohm (1981 and 1982), Bohm and Russell (1985) examine the cost and benefit of waste return to determine the efficient levels of deposit, refund, and return rate in DR systems. The benefit associated with waste return is the externality reduced plus the reuse value and cost saving from alternative disposal methods, while the cost is generated from the return process. Bohm proposed that a deposit should equal the externality cost generated from waste and a refund should equal the social willingness to pay (SWTP) for reducing externalities, which depends on the amount of waste return.

For a firm, the return cost minus the disposal cost avoided determines the propensity-to-return (***PTR***) of used products. A ***PTR*** is assumed to increase with the increase in the quantity of return. The benefit associated with waste return is the refund if the waste has no residual value. A firm will return its waste at the level where marginal cost of return equals the refund rate. When the waste has reuse value, the benefit of return to the producer will be the refund rate plus the reuse value. When the refund rate plus the reuse value is always greater than ***PTR***, all of the waste will be returned to recycling centers. If refund plus reuse value is less than ***PTR*** for a portion of the wastes, according to the condition of marginal benefit equaling marginal cost of return, the firm's optimal volume returned falls short of the total volume of used products disposed, thereby implying that only part of the deposit is refunded. Thus, because not everyone

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[3] Bohm (1981 & 1985), OECD (1991) and Macauley et al.(1992) have discussed in more detail the economic incentive of this bond in their studies.

returns his/her wastes, the surplus from DR systems will be created. This surplus can be redistributed to compensate the losers within this scheme. This result of a DR system is illustrated in figure 1.

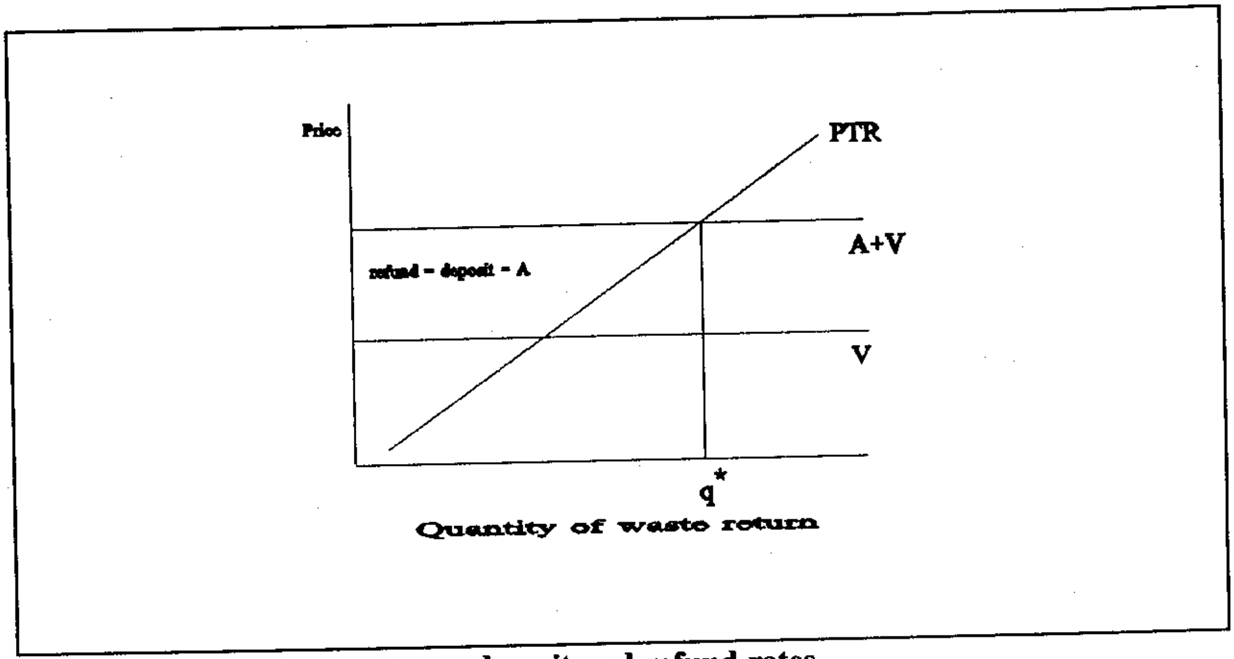

Figure 1. Propensity-to-return, deposit and refund rates.

In figure 1, ***PTR*** is the propensity to return waste products or the supply of returned products. ***V*** is the reuse or recycling value of the waste. ***A*** is the externality cost or the social marginal willingness to pay for reducing waste-related externalities. ***A** and **V*** are assumed to be constant. A deposit or refund is set equal to the externality cost A. The condition ***PTR*** equals $A+V$ determines the optimal return rate q^*.

Bohm examines the welfare change for each affected party of a DR system. The impact of a DR system on the demand for a polluting product depends on the available disposal alternatives. If the unit costs of alternative disposal, such as landfill disposal, (C_d) are higher than the unit costs of return (C_r), the consumer gets a cheaper alternative to dispose of his used products, and then the aggregate demand for this polluting product will increase under DR systems. If $C_r > C_d$, the demand for this polluting product tends to decrease because the disposal cost increases under this scheme. For the producers of the polluting product , the profit function will show the impacts of DR systems on firms. If the demand for this polluting product increases, profit as well as output in producing this waste-generating product will increase under DR systems. On the other hand, if the demand for this polluting product decreases, DR systems will lead to a reduction in profit. The winners include the beneficiaries of a reduction in external effects and the owners of specialized treatment firms. The losers are those whose costs for returning the product exceed the costs for the alternative disposal and the owners of the firms whose output is reduced due to a DR system. Because there are the winners and losers, Bohm proposed a compensating plan. Return cost is the crucial variable in a DR system. The government can compensate the losers by using the surplus from this DR system to subsidize return costs or by providing collection services. As a result, the likelihood that demand and profit would decrease due to DR systems will be reduced.

Lee, Graves, and Sexton (1990) examine a mandatory deposit on beverage containers as a means of controlling litter. They model the effects of a deposit on litter generation and recovery from a dynamic perspective. The objective of a mandatory deposit on a polluting product is to maximize the present value of the net social gains from littering subject to the litter stock accumulation process. The gains are calculated as the private benefit from littering less the aesthetic cost associated with littering and the cost of litter recovery. They conclude that in present value terms, the marginal benefit from littering should equal the marginal aesthetic cost of littering plus the marginal cost of increasing the litter stock. Thus, the efficient rates of littering and litter recovery will be achieved when a deposit equals the summation of these two costs. In addition, they propose that a littering fine imposed on the product will generate less littering. Lee et al. do not examine explicitly the effect of the refund.

Dobbs (1991) examines three schemes imposed on a litter-generating consumption good in controlling littering -- tax, subsidy, and DR system (the combination of tax and subsidy in his model). Some consumers of this product litter but the others do not. A tax and a subsidy are used to control litter. The tax equals the marginal social cost of littering, and the subsidy equals the marginal social cost of not littering. Dobbs calculates the economic welfare of this program by measuring willingness to pay minus social costs. In a competitive market, welfare can be expressed as the sum of consumer surplus and producer surplus minus the externalities generated by littering. The policy-maker can maximize total social welfare either by imposing a tax or a subsidy. Dobbs concludes, however, the tax alone is unable to distinguish between the social costs imposed by litter and non-litter, while the user subsidy alone provides no incentive to consumers to produce less wastes. When the combination of optimal levels for disposal tax and user subsidy is used, the deposit equals marginal social cost associated with litter and the refund equals the externalities reduced by non-littering. Dobbs also proposes that a DR system can be extended to other packaging and paper wastes, but it should depend on the cost of implementation. He claims that as the resource or environmental good becomes scarce, marginal social costs increase over time, so a DR system is desirable because it will entice individuals to generate less littering. In this model, however, he ignores the cost of returning the used product.

Macauley, Bowes and Palmer (1992) apply a DR system to control hazardous waste disposal. They include the costs of recycling, proper disposal, and illegal dumping in examining the net social gains from a DR program to control externalities. They assume that there is a maximum quantity that can be recycled such that beyond this level, proper disposal is required. No externality is generated from recycling in their model. In addition to recycling, there are two methods of waste disposal. One method is illegal dumping, which generates externalities, while the second is proper disposal, such as safeguard landfill disposal, which is assumed to generate no external effect. In the case of illegal dumping, private disposal costs are lower than the social disposal costs. For proper disposal, the private and social disposal costs should be equal, i.e., absence of externalities. Otherwise, the social disposal costs will be larger than the private disposal costs. By setting a deposit equal to the difference between the social cost and private cost of illegal dumping, the adoption of recycling as well as proper disposal methods is encouraged. When a refund is employed, it will increase the opportunity costs of not recycling or illegal dumping. Thus, a DR system will encourage recycling as well as proper disposal.

Porter (1978,1983) examines the effectiveness of Michigan's DR system on beverage containers using a cost-benefit analysis. He identifies the benefits for this scheme as reducing the costs of litter (both pickup and "eyesore" costs), solid waste collection, and container costs. The costs of this DR system include costs associated with consumer inconvenience from returning containers, and the increase of costs from production and distribution process (such as the costs of sorting and rinsing containers). He concludes that the effectiveness of a DR system depends on the average subjective value of the time taken by consumers to return waste as well as the value of the aesthetic effect associated with litter reduction. If the latter value outweighs the former value, the social well-being increases and a DR system is desirable. The empirical results from Porter's study indicate that the price of a product under a DR system increases and the quantity demanded decreases, which reduces the consumer surplus in the consumption of this product.

Pratt and Schwartz (1989) illustrate how to apply a DR scheme to manage the hazardous waste disposal of small quantity generators. They argue that an individual disposal decision depends on the size of the refund and the cost of alternative disposal methods (such as illegal dumping). They calculate cost savings from illegal disposal as the amount of legal disposal costs minus the refunds. When these savings are negative, a firm will properly dispose of its waste. A refund must be large enough to cover the costs between illegal dumping and legal disposal. Thus, an effective refund should be large enough to encourage firms to adopt desirable disposal methods. In their study, however, they do not discuss how a DR system affects the demand for this DR imposed product.

From these studies, we arrive at several conclusions. First of all, externalities generated from waste disposal affects social well-being. These externalities come from either production processes or consumption processes, or both. The impacts from externalities could be positive (Lee et al., 1990) or negative. Secondly, when a DR system is employed to control waste disposal, it affects production as well as consumption. Third, a DR system involves a return (or recycling) process for waste disposal. Thus, the elements that determine the deposit and refund rates should include social welfare functions, the source and measurement of externalities from production or consumption, technology of the production and externality-reduction processes. Fourth, there is no general framework to incorporate how a DR system affects externalities as well as well-being. These studies either look only at partial impacts of DR systems or construct a very complicated framework. Most of these authors assume the marginal cost of an externality to be exogenous and constant. This assumption ignores the interrelationship of externality, production,.and consumption. For instance, Solow's suggestion - a deposit set equal to the cost of most harmful disposal method - ignores the benefits of externalities to people who litter. To explore the efficiency conditions, the next section constructs a general framework to account for the relationships among externalities, consumption, production, and waste generation as well as return processes.

III. GENERAL FRAMEWORK FOR DEPOSIT-REFUND SYSTEMS

In this section the initial objective is to determine whether DR systems can be Pareto efficient as a means of controlling externalities of waste material. This general model developed in section III identifies deposit and refund rates that are Pareto efficient. This model is subsequently extended to examine three operational issues: the difference between a DR system and alternative schemes such as product charges, user fees, fines, and recycling subsidies, the effect of imposing a balanced budget constraint, and the combination of a DR system with a penalty scheme.

Baumol and Oates (1988) consider a competitive general equilibrium framework, where a production process generates externalities that impose disutilities on society. They discuss a tax/subsidy strategy that will induce individuals to behave in a manner compatible with the requirements for Pareto efficiency. In their model, the only way to reduce externalities is for the firm generating the externality to reduce production.

Extending Baumol and Oates' framework, in the DR model developed below[4], the firm

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[4]. I am grateful for the suggestion from Dr. Hoehn.

is assumed to be able to use two externality-reduction strategies -- a waste-return process and a production-reduction process. For simplicity, the economy is assumed to consist of one representative agent, one single production agent, three goods, and one negative externality[5]. These three goods can be used either on consumption or on production. One good (output) is assumed to be produced by the other two goods (inputs). As inputs, one good will generate waste while the other one does not. We assume that these goods do not generate any externality if they are used for consumption. The decisions made by the consumption process and by the production process are separate. In this model, the market is assumed to be perfectly competitive, the representative agent is to maximize its utility, and the firm is to maximize its profit. Furthermore, the model assumes that the production process generates hazardous waste material by using a polluting input, such as mercury, cadmium, or solvent. Improper disposal of the waste, results in an externality such as soil or water contamination. The externality is expected to enter the utility function of the representative agent. The firm can reduce the occurrence of an externality by returning waste to a recycling center. The firm can extend this process to include a recycling process or other proper disposal method.

To account for the impacts of the production and its externality on economic welfare, the utility function of a representative individual is used. The utility of the individual, $u(x_{1c} , x_{2c} , x_{3c} , e)$, depends on consumption goods x_{ic} ($i = 1, 2, 3$)[6], and the level of the externality, e. Market goods have a positive impact on well-being ($u_i > 0$, for $i = 1, 2, 3$)

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[5]. This representative agent can be thought of as the whole economy, which consists of many individuals. There goods are composed of three vectors of goods.

[6]. To specify the notations clearly, I use only one word in subscript to denote first derivative while two words in subscript for goods or prices.

while the externality has a negative impact ($u_e < 0$). Utility is assumed to be concave in x_{ic} and convex in e. This implies that the marginal utility of x_{ic} is diminishing and the marginal disutility of e is increasing.

Both the consumption goods and the externality are assumed to be produced from a single firm's production process. The production set is denoted by $f(y_{1f} , y_{2f} , y_{3f} , s) \leq 0$, where $y_{1f} .. y_{3f}$ are net outputs and s is waste. Net outputs have a positive impact on the production set ($f_i > 0, i = 1, 2, 3$), while the waste material, s , has a negative impact ($f_s < 0$). The production set is assumed to be convex in its net outputs. This implies that the marginal product of inputs is diminishing (Varian, 1992). y_{if} can be used either for consumption or for production. The sign of y_{if} is positive if it is an output and is negative if it is an input[7]. The waste material is assumed to be produced by y_{3f} when it is used as input, while the process itself is denoted by $s = g(y_{3f})$. Increasing y_{3f} (i.e. reducing the use of input y_{3f}) decreases the generation of waste ($g_3 < 0$). One unit of input generates at most one unit of waste (such as beverage containers), so the maximum amount of waste will not exceed the total amount of input. This implies that the marginal waste product for the polluting input will be less than one, thus $-1 \leq g_3 < 0$. The waste is possible to generate an externality if it is not disposed properly.

Externalities can be reduced by returning waste to a recycling center. The return process is denoted by $b(y_{1b} , y_{2b} , \delta) \leq 0$, where y_{1b} and y_{2b} are net outputs from production and serve as inputs used for return, and δ is the amount of waste returned for recycling. The

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[7] This expression has a major advantage. In an economy with multiple inputs and outputs, it describes how one firm can model its input, y_{if} , the output of another firm, by treating y_{if} as a negative output (Varian, 1992).

return process needs resources y_{1b} *and* y_{2b} . For example, the principal waste product from pesticides includes containers that may contain harmful residues. The return of pesticide containers can reduce the occurrence of this negative externality. The return process uses resources such as fuel and labor. The inputs and the amount of waste returned for recycling have positive effects on the return process ($b_z > 0$, **for** $z = y_{1b}$, y_{2b} , **and** δ). The return process is assumed to be convex in net outputs as well as the amount of waste return. For simplicity, the recycling process is assumed to incur no externality. Therefore, the amount of negative externalities actually generated by the firm is the total amount of waste generated from the production process minus the amount of waste returned for recycling, i.e., $e = s - \delta$.

The consumption, production, and return processes also are subject to the available resources constraints, $x_{ic} - y_{if} - y_{ib} \leq a_{ic}$, where a_{ic} is the initial resource endowment of the economy, $i = 1, 2, 3$. This implies that the total amount of consumption cannot be greater than the sum of production and initial endowment.

From these assumptions, the Pareto efficient conditions and profit-maximization conditions of a firm are derived in the following context to determine the efficient levels of deposit and refund.

3.1 PARETO EFFICIENT CONDITIONS

The necessary conditions of Pareto efficiency in controlling the externality is derived from maximizing the representative utility function subject to the technology and resource constraints. The utility is influenced by the choice of activity levels, such as the consumption level (x_{ic}), input usage (y_{if} *and* y_{ib}), output levels (y_{if}), and the amount of waste returned

(δ). The problem is formulated

$$Max \quad u(x_{1c}, x_{2c}, x_{3c}, e) \qquad \textit{[representative utility function]} \tag{1}$$

$$s.t. \quad f(y_{1f}, y_{2f}, y_{3f}, s) \leq 0 \qquad \textit{[transformation function of production technology]} \tag{2}$$

$$s = g(y_{3f}) \qquad \textit{[waste-producing process]} \tag{3}$$

$$b(y_{1b}, y_{2b}, \delta) \leq 0 \qquad \textit{[return process]} \tag{4}$$

$$e = s - \delta \qquad \textit{[externality actually produced]} \tag{5}$$

$$x_{ic} - y_{if} - y_{ib} \leq a_{ic} \qquad \textit{[resource constraints, } i = 1, 2, 3 \textit{]} \tag{6}$$

$$\delta > 0, \quad x_{ic} \geq 0, \quad e > 0, \quad s > 0.$$

The Lagrangian function is formed by substituting equations (5) and (3) into equation (1) and (2). The necessary conditions for Pareto efficiency are derived by maximizing the Lagrangian with respect to consumption good, x_{ic}, net output, y_{if} and y_{ib} **(for** $i = 1, 2, 3$) and the amount of waste returned for recycling, δ.

$$Max\ \mathcal{L} = u(x_{1c}, x_{2c}, x_{3c}, g(y_{3f}) - \delta) - \beta_{1f} f(y_{1f}, y_{2f}, y_{3f}, g(y_{3f}))$$

$$- \beta_{2b}\, b(y_{1b}, y_{2b}, \delta) + \Sigma_{i=1}^{3} \mu_{ia} [a_{ic} - x_{ic} + y_{if} + y_{ib}], \quad where\ \beta_{1f}, \beta_{2b}, \mu_{ia} \geq 0.$$

β_{if}, β_{ib}, *and* μ_{ia} are Lagrangian multipliers. Interior solutions are assumed for the first order conditions:

$$\text{For } x_{ic} : u_i - \mu_{ia} = 0, \ for\ i = 1, 2, 3; \tag{8}$$

$$y_{if} : -\beta_{1f} f_i + \mu_{ia} = 0, \ for\ i = 1, 2; \tag{9}$$

$$y_{ib} : -\beta_{2b}\, b_i + \mu_{ia} = 0, \ for\ i = 1, 2; \tag{10}$$

$$y_{3f} : u_e\, g_3 - \beta_{1f} (f_3 + f_s\, g_3) + \mu_{3a} = 0; \tag{11}$$

$$\delta : -u_e - \beta_{2b}\, b_\delta = 0. \tag{12}$$

By solving equations (8) through (10), we obtain the shadow prices of consumption (μ_{ia}), production (β_{1f}), and return process, (β_{2b}). Putting these prices into equations (11) and (12), the efficient level of the polluting input (y_{3f}), and the efficient amount of waste returned for recycling (δ) can be obtained. These results are presented below:

$$u_i = \mu_{ia}, \text{ for } i = 1, 2, 3; \tag{8'}$$

$$\beta_{1f} = u_i / f_i, \text{ for } i = 1, 2; \tag{9'}$$

$$\beta_{2b} = u_i / b_i, \text{ for } i = 1, 2; \tag{10'}$$

$$u_e g_3 + u_3 = (u_i / f_i)(f_3 + f_s g_3); \tag{11'}$$

$$-u_e = (u_i / b_i) b_\delta . \tag{12'}$$

Equation (8) determines the necessary conditions of Pareto efficiency for consumption goods. This condition yields $u_i = \mu_{ia}$. This implies that the shadow price of a consumption good (μ_{ia}) will equal its marginal utility or consumer's marginal willingness to pay (u_i), where $i = 1, 2, 3$. Equations (9) and (9') reveal the necessary conditions of Pareto efficiency for producing the net outputs y_{1f} and y_{2f}, where the marginal benefit equals the marginal cost. For instance, if y_{1f} is an output, $\beta_{1f} f_1$ denotes the marginal cost of output while μ_{1a} *or* u_1 denotes the marginal benefit of output. If y_{2f} is an input, $\beta_{1f} f_2$ denotes the marginal product of this input while μ_{2a} or u_2 denotes its marginal cost. Similarly, equations (10) and (10') yield the necessary conditions of Pareto efficiency for employing resources y_{1b} and y_{2b} to return waste, where the marginal benefit ($\beta_{2b} b_i$) again equals the marginal cost of return (u_i).

From equations (11) and (11'), the necessary condition for Pareto efficient use of polluting input y_{3f} should be at the level where the marginal social costs, denoted by $u_e g_3 + u_3$, equal the marginal social benefits, denoted by $(u_i / f_i)(f_3 + f_s g_3)$, $i = 1, 2$. The costs and the benefits are derived from two components -- the polluting input (y_{3f}) and its waste. y_{3f} yields the marginal benefit, the value of marginal output $(u_i / f_i) f_3$, and incurs the marginal cost, or the purchasing cost u_3. The waste could generate an externality and impose an additional social cost $u_e g_3$ on the representative agent, while it creates an additional marginal benefit $[(u_i / f_i) f_z g_3]$ on the production process as well. The shadow price of the polluting input, as a result, equals $u_e g_3 + u_3$.

For the same reason, equations (12) and (12') yield $-u_e = (u_i / b_i) b_\delta$, which denotes the necessary condition of Pareto efficient waste return. This result illustrates that the marginal cost of returning wastes, $(u_i / b_i) b_\delta$, should equal marginal disutility reduced, $-u_e$. This marginal disutility reduced is the shadow price of waste return.

From the fundamental welfare economics theorem, under some conditions including convexity of preference and technology, a Pareto efficiency can be supported by a competitive equilibrium. That is, there exists a set of prices such that a Pareto efficiency is a competitive equilibrium. These prices will reflect the true social costs of each good. If the market prices of goods x_{ic} (for $i= 1, 2, 3$) or y_{if} *and* y_{ib} (for $i= 1, 2, 3$) are the same as their shadow prices, this economy will achieve Pareto efficiency. Therefore, if this externality can be charged at its shadow price, Pareto efficiency is achieved. However, the issue associated with externalities is that there is no existing market. Due to externalities, the social costs and private costs diverge.

On the production side, when there is no market for an externality, the production agent will get an additional benefit without paying the cost by using the polluting input y_{3f}. The production agent will only account for the benefit but not the cost of the externality. The input and output levels will not be the Pareto efficient levels. From equation (11'), the marginal social cost and the marginal private cost of the polluting input y_{3f} differ. The former is denoted by the purchasing cost u_3 plus marginal disutility $u_e\, g_3$, while the latter is denoted by the purchasing cost u_3 . Because this production process does not pay full social costs of using polluting input y_{3f} , it ends up using too much of the polluting input, generating too much externality, and producing too much output. This relationship is illustrated in figure 2.

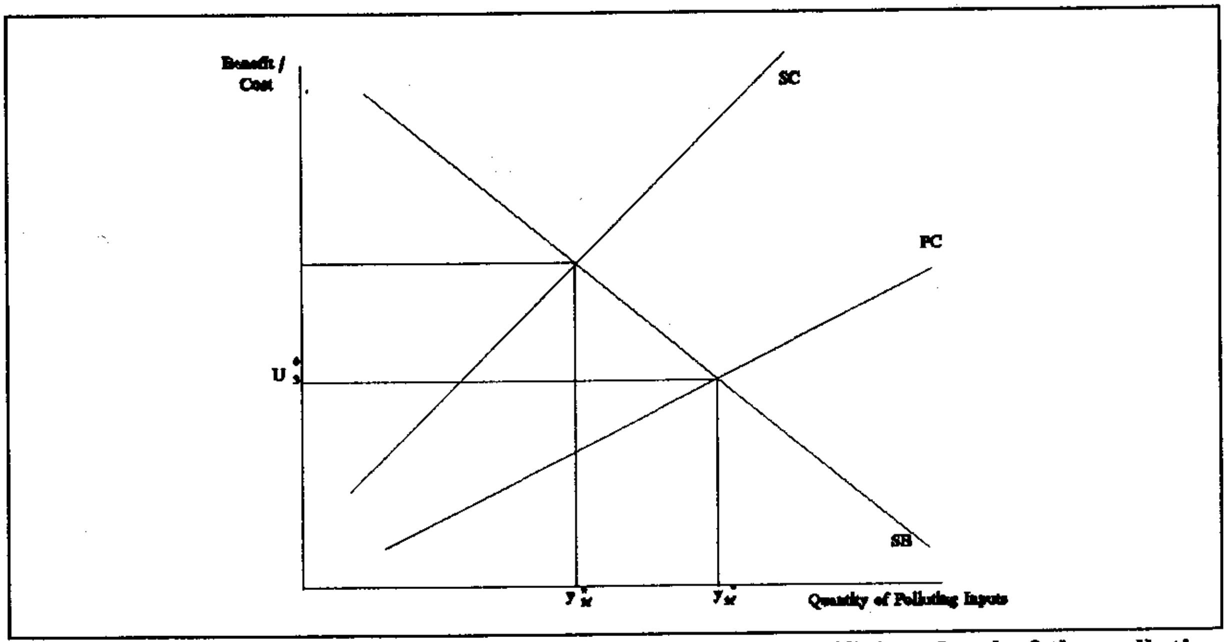

Figure 2. The social benefit, social cost, private cost, and efficient level of the polluting input.

In this graph, for the polluting input, ***SB*** depicts its marginal social benefit, ***SC***, the marginal social cost, and ***PC***, the market price. The Pareto efficient usage of polluting input y_{3f} should be y_{3f}^* where the value of marginal output $(u_i / f_i)(f_3 + f_s\, g_3)$ equals the marginal social cost $u_e\, g_3 + u_3$. Due to failure to face the true social costs, an individual uses the input y_{3f} at the level y_{3f}^o and pays the private cost u_3^o . This result shows that without accounting for the cost of externality, the use of the polluting input is greater than in the case of Pareto efficiency, while the private cost of using this input is lower than the social cost. Because y_{3f}

has a positive impact on production, the output level will also be greater than the efficient level.

From the above analysis, the difference between the social cost and the private cost of a polluting input is the externality generated by the firm. This externality is measured by the marginal damage costs, including health damage and aesthetic costs, that are directly related to production and waste-return processes. The magnitude of externalities depends on their impacts on a utility function. CFM (chlorofluoromethanes), for example, will deplete the ozone layer and thus damage human health if an agent improperly disposes of the CFM-containing waste. Thus, the externalities generated could be very large.

For the same reason, if the externality is unpriced, the individual only accounts for the return cost, $(u_i / b_i)\, b_\delta$, but not the benefits for the reduction of externality, $-u_e$. In this case, the firm fails to take into account the social benefits of reducing disutility, and the amount of waste returned for recycling therefore is less than the efficient level from a social standpoint.

There are two solutions to the existence of externalities. The first solution is to assign non-attenuated property right to individuals and allow them to negotiate with each other. When the transaction cost is low, the representative agent will negotiate with the production agent. Therefore, Pareto efficiency can be achieved. However, externalities share the same characteristics as public goods. The number of involved agents is always large such that the transaction costs are high. The other solution is to employ a policy such as a tax or a subsidy to provide a price for externalities and generate the same results as Pareto efficiency. A DR system is employed in this paper to give prices on externalities. A deposit is imposed to account for the externality generated from a production process, while a refund is issued to account for the externality reduced by a return process. The impact of a DR system as well as the efficient levels of deposit and refund are discussed in the following sections.

3.2 THE EFFICIENT LEVELS OF DEPOSIT AND REFUND

If a DR system can induce a firm to choose the same levels as those derived from the necessary conditions for Pareto efficiency, the deposit and refund rates are efficient. The objective of this section is to determine the efficient rates of deposit and refund. To address this issue, we should first examine the decision process of a firm.

3.2.1 Profit-Maximization Conditions of a Firm

A firm is assumed to maximize its profit subject to technology constraints in a competitive market. This firm employs the production process $f(y_{1f} , y_{2f} , y_{3f} , s) \leq 0$ and the return process $b(y_{1b} , y_{2b} , \delta) \leq 0$. Let d be the deposit rate which is added to the price of the polluting input y_{3f} , and r be the refund rate which is paid for each unit of waste returned for recycling. Given a set of prices, $p_{1y} .. p_{3y}$, d and r, a firm will maximize its profit with respect to its net outputs y_{if} , y_{ib} and δ subject to the technology constraints of production and return processes. The profit maximization problem is set up such that,

$$\begin{aligned} Max \quad & \pi = p_{1y} (y_{1f} + y_{1b}) + p_{2y} (y_{2f} + y_{2b}) + (p_{3y} + d) y_{3f} + r\delta \\ s.t. \quad & f(y_{1f} , y_{2f} , y_{3f} , s) \leq 0, \\ & s = g(y_{3f}), \\ & b(y_{1b} , y_{2b} , \delta) \leq 0, \ and \ \delta > 0. \end{aligned}$$

Substituting $s = g(y_{3f})$ into the production function yields the following Lagrangian function:

$$\begin{aligned} Max \ \mathcal{L} = & p_{1y} (y_{1f} + y_{1b}) + p_{2y} (y_{2f} + y_{2b}) + (p_{3y} + d) y_{3f} + r\delta \\ & - \lambda_{1f} f(y_{1f} , y_{2f} , y_{3f} , g(y_{3f})) - \lambda_{2b} \, b(y_{1b} , y_{2b} , \delta), \text{ where } \lambda_{1f}, \lambda_{2b} \geq 0. \end{aligned}$$

The profit-maximization conditions of this firm are stated as follows:

$$\text{for} \quad y_{1f} \textit{ and } y_{2f}: \ p_{iy} - \lambda_{1f} f_i = 0, \ i = 1, 2; \qquad (13)$$

$$y_{1b} \textit{ and } y_{2b}: \ p_{iy} - \lambda_{2b}\, b_i = 0, \ i = 1, 2; \qquad (14)$$

$$y_{3f}: \ p_{3y} + d - \lambda_{1f}(f_3 + f_s\, g_3) = 0; \qquad (15)$$

$$\delta: \ r - \lambda_{2b}\, b_\delta = 0. \qquad (16)$$

Equations (13) and (14) yield the profit-maximizing conditions for producing net outputs y_{1f} and y_{2f} as well as y_{1b} and y_{2b}. By solving these two equations, we obtain the firm's shadow prices of production (λ_{1f}), and return process, (λ_{2b}). Putting these prices into equations (15) and (16), we get the profit-maximizing level of the polluting input (y_{3f}), and the profit-maximizing amount of waste returned for recycling (δ). These results are presented below,

$$\lambda_{1f} = p_{iy} \,/\, f_i\,, \ i = 1, 2; \qquad (13')$$

$$\lambda_{2b} = p_{iy} \,/\, b_i\,, \ i = 1, 2; \qquad (14')$$

$$p_{3y} + d = (p_{iy} \,/\, f_i)(f_3 + f_s\, g_3); \qquad (15')$$

$$r = (p_{iy} \,/\, b_i)\, b_\delta\,. \qquad (16')$$

From equations (13') and (14'), λ_{1f} and λ_{2b} are the shadow prices of the production and return processes respectively. A firm increases production of net outputs until it reaches the level where marginal cost equals marginal benefit. When y_{1f} is an output, $\lambda_{1f} f_1$ denotes the marginal cost of output while p_{1y} denotes the marginal benefit of output. When y_{2f} is an input, $\lambda_{1f} f_2$ denotes the marginal product of this input while p_{2y} denotes the marginal cost of using this input. Similarly, this firm will return its waste at the level where the marginal benefit equals marginal cost of return.

Equation (15') illustrates the firm's use of polluting input y_{3f}. When a deposit d is imposed, the cost of using this input becomes the market price plus a deposit, while the firm's marginal benefit is the value of marginal product of both y_{3f} and externality e, denoted as $(p_{iy} / f_i)(f_3 + f_e g_3)$, *for* $i = 1, 2$. A deposit results in an increase in marginal cost of the polluting input and thus the value of marginal product of polluting input should be larger than in the case of no deposit. According to the concept of diminishing marginal product, the output level as well as the use of polluting input y_{3f} should decrease.

Similarly, equation (16') determines the amount of waste returned for recycling, where the marginal cost of return $(b_i / p_{iy})\, b_\delta$ equals a refund r. A refund can increase the marginal private benefit of waste return and thus increase the amount of waste return.

Equations (15') and (16') have implications for cost-benefit analysis. A deposit increases the cost of a polluting input and thus reduces the output. This can be identified as a cost of a deposit. A refund increases the level of waste return that increases resources used in the return process. This is a cost of a refund. On the other hand, a DR system creates benefits by reducing externality. A DR system can increase social well-being if the total benefits are larger than the total costs. What deposit and refund rates will induce a firm to produce at an efficient level is discussed in the next section.

3.2.2 The Efficient Levels of Deposit and Refund

To derive the efficient level of a deposit or a refund rate, a firm's maximization conditions should generate the same results as the Pareto efficient conditions derived previously. In a competitive market for a good that generates no externality, the market price will reflect the shadow price or the marginal utility from consuming this good. Goods y_{1f} and y_{2f} do not generate any externality. Thus, their market prices reflect the true social costs of consuming these two goods. Hence the shadow price for production, β_{1f} (derived from a Pareto efficient condition, equation (9')), should equal λ_{1f} (derived from a firm's maximization condition, equation (13')). Similarly, the shadow price of the return process, β_{2b} (derived from Pareto efficiency condition, equation (10')) should equal λ_{2b} (derived from a firm's maximization condition, equation (14')).

The polluting input y_{3f} generates an externality such that the social costs and the private costs differ because the externality is not priced. The social damage cost, the extent of departure from the Pareto efficient level (equation (11')), is the amount of externality generated from the use of the polluting input, equal to $u_e\, g_3$. This is the marginal disutility from the waste generated by each unit of the polluting input y_{3f}, or the shadow price of externalities. Equation (15') determines the profit-maximization condition for the polluting input. When equation (15') is the same as equation (11'), the Pareto efficiency can be achieved. Therefore, an efficient deposit rate should be set equal to marginal damage generated from the use of y_{3f}. That is,

$$d = u_e\, g_3 = \lambda_{1f}(f_3 + f_s\, g_3) - p_{3y}; \qquad (17)$$

When a deposit rate is set at an efficient level, a firm uses the polluting input y_{3f} at the level where the marginal social benefit is equal to the marginal social cost. The marginal social benefits are denoted by $\lambda_{1f}(f_3 + f_s\, g_3)$, where λ_{1f} is the shadow price of production, f_3 is the marginal product of polluting input y_{3f} , and $f_s\, g_3$ is the marginal product of the waste generated from the polluting input. The marginal costs of using this polluting input are $p_{3y} + d$. Thus when a deposit d equals the marginal damage cost $u_e\, g_3$, the firm, as a result, pays the full social costs of the polluting input, and will produce at efficient levels.

When the marginal disutility of an externality (u_e) or the marginal waste product

(g_3) from the polluting input is large, the deposit rate will be high. For example, a pesticide container has a higher damage cost than a beverage container, so the deposit for the former is higher than for the latter. Another example consists of two different production processes which use oil as an input. One process generates 0.5 gallon of waste oil while the other generates 0.1 gallon of waste oil for each gallon of oil use. If the proportion of waste oil generated from a production process can be identified and the refund rate of these two waste oils are the same, the deposit for the firm generating less waste oil should be less. However, the technical feasibility is required to identify the marginal waste product between different processes. As the externality is priced by imposing a deposit, the firm then faces higher cost of using the polluting input than in the case of no price for the externality. As a result, the output of the firm which uses the polluting input will fall. The externality will be reduced by decreasing production.

Similarly, the return process can reduce the disutility caused by the improper disposal of waste. A refund is employed to reflect the benefit of a return process. From equation (12') and (16'), if a refund is equal to the reduction of disutility caused by the externalities ($-u_e$), which denotes the shadow price of per unit of waste returned for recycling , a firm will return its externality-generating waste at the efficient level.

$$r = - u_e = \lambda_{2b} \, b_3 \, ; \tag{18}$$

A profit-maximizing firm will set the level of waste return such that the marginal cost of return process is equal to the refund (the benefit from returning waste). By assigning a price to the reduction of disutility by returning waste, the firm is encouraged to return the waste to a recycling center at the efficient level. This return process thus reduces the occurrence of externality.

Equations (17) and (18) have implications for cost-benefit analysis. The objective of DR systems is to increase overall social well-being. As the model shows, a DR system serves to internalize Pareto relevant external effects. The externality can be reduced either by reducing the production of a waste-generating process or by returning the externality-generating waste to a recycling center. On the other hand, a DR system increases the costs of production as well as of return processes. The efficient levels of deposit and refund should balance these costs and benefits. From the framework developed, both deposit and refund rates are set proportional to the magnitude of disutilities. The deposit or refund rate might thus depend on the size of the waste. For example, pesticides may be packed in either small or large containers. Obviously, the externalities caused by the latter are greater than the former. The amount of deposit for large containers, as a result, should be higher than for small containers. When a DR system accounts for externalities potentially incurred in terms of container size rather than in terms of the number of containers, firms will avoid substituting large containers for small containers. This will then generate more externalities per unit.

3.2.3 The Relationship between the Deposit Rate and Refund Rate

One issue arises whether or not the deposit rate should equal refund rate. From equations (17) and (18), a deposit rate is proportional to a refund rate by g_3 (i.e. $d / r = -g_3$). If the use of y_{3f} per unit generates one unit of waste, the deposit rate should equal the refund rate (i.e. $g_3 = -1, d = r$). Otherwise, a refund rate ($-u_e$) should be larger than a deposit rate ($u_e g_3$), and the difference depends on the marginal waste output of y_{3f} (recall that from the assumption, $-1 \leq g_3 < 0$). This is because a deposit is imposed based on the amount of polluting input, while a refund is issued directly to the quantity of waste. If part of the input is embodied or consumed in the output of the production process, the quantity of waste product that can be returned for refund will be less than the total amount of input. If the marginal waste output ($-g_3$) is close to one, the refund rate will be close to but larger than the deposit rate. When the marginal waste output is much less than one, the difference between a deposit rate and a refund rate will be much larger. If the marginal waste output from each production process can be identified, the deposit or refund rate will be more effective in reflecting the occurrence of externalities.

From a review of the literature and the theoretical framework, the sources, valuation approaches, and impacts of externalities, deposits, and refunds can be summarized in Table I. From Table I., the Pareto efficiency conditions depend on the impacts of three elements: externality, deposit, and refund. The externalities from improper disposal of waste are directly related to a production process or a consumption activity. The estimation of marginal damage cost of externalities includes aesthetic costs, health costs, damage costs and pick-up costs. These externalities have negative impacts on individuals' utility functions and other firms' production functions. The more hazardous this waste is, the higher will be the level of externalities that will occur. On the other hand, the externalities increase benefits by decreasing marginal costs of firms' production, since firms do not pay the full disposal cost of waste. In this situation, the input and output levels of each firm are higher than the efficient levels.

This model also points out that imposing an efficient deposit rate on a polluting input will entice firms to produce at efficient levels. The amount of a deposit should account for the relationship between benefits and costs of the externalities. Setting the deposit equal to the

Table I. The impacts of externalities and deposit refund systems:

Elements	Sources	Valuation approaches	Impacts
Negative externality	wastes: - improper disposal - littering	marginal damage cost (MDC)	- positive impacts on production - negative impacts on social well-being
Deposit	polluting inputs or outputs	potential marginal damage cost (MDC) of improper disposal from a polluting input	- produce at efficient levels - reduce externalities by reducing the use of waste-generating input - increase cost of waste-generating input
Refund	waste: - return - proper disposal which reduces externalities	MDC from waste that is avoided[8]	- encourage the adoption of less damaging disposal method - avoid externality by returning waste to a recycling center - increase the return cost

marginal damage cost incurred from the improper disposal of waste will induce firms to account for full social costs and produce at an efficient level from a social standpoint. The benefits of a deposit come from the reduction of externalities by using less polluting input which means less waste generated. The costs of a deposit are incurred through the higher costs to firms of purchasing polluting inputs. The increase in production costs will thus reduce the use of a deposit-imposed input, and thereby reduce the output level. If a deposit is set at a very high

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[8]. see equation (18).

level, externalities will be decreased by reducing the production. Then, the consumer surplus and producer surplus also decrease.

When the waste is properly disposed of, the refund is issued. The refund rate should reflect the marginal damage cost avoided. The benefits of a refund, again, are equal to the reduction of the externality from waste return. A refund will provide an incentive for proper disposal of hazardous waste. The costs of a waste return are related to the resources used in the return process.

The change in disposal costs due to the implementation of a DR system is not uniform across firms. Disposal costs for firms already returning or properly disposing of waste will not increase with the adoption of a DR system. However, for firms employing cheaper alternatives prior to the implementation of a DR system such as illegal dumping, disposal costs may increase.

Profit-maximizing firms' disposal decisions depend on the costs of alternative disposal methods as well as the net benefits from waste return, or the opportunity costs when a firm does not return its waste (refunds minus return costs).. If there is no cost for illegal dumping, a profit-maximizing firm will return its waste to a recycling center only when the refund is at least as large as the return cost. The refund rate, as Solow suggested, can vary across different disposal methods and will encourage the adoption of socially preferred disposal methods. For instance, if the damage can be completely eliminated by recycling, users of this deposit-imposed product can receive the full amount of their deposits. Otherwise, only part of the deposit is refunded depending on the externalities reduced.

3.3 EXTENSION ISSUES OF DR SYSTEMS

This section examines three operational issues - comparing alternative schemes and DR systems, imposing a balanced budget constraint, and combining a DR system with a penalty.

3.3.1 Comparison Between Alternative Schemes and a DR System

In addition to DR systems, there are several policies that have been proposed to control hazardous waste disposal, such as a product charge, a user fee, a penalty, or a recycling subsidy (Bohm, 1981; Miedema, 1983; Opschoor and Vos, 1989; OECD, 1991). All of these policies are employed to impose a price for externalities. There are several differences among these policies. The main difference lies in what is actually charged. A DR system is designed to impose costs on non-returned waste. A product charge can be placed either on the raw material content of products, or on waste-generating inputs. A user fee is charged on the disposal of waste materials. A penalty is placed on illegally discarded waste that has been detected. A subsidy is usually proposed to recycling processes. The policy adopted results in a different distribution of effects. The second difference is, all of these policies result in different transaction costs in monitoring. The third difference is, these policies have different impacts on the production as well as the waste return. The following discussion shows these differences among policies.

A DR system imposes charges on the non-returned waste $(s - \delta)$. A deposit is a prepayment on the purchase of a polluting input. When the waste is returned to a recycling center, a refund is issued. As section 3.2 has shown, a DR system will entice a firm to produce and return waste at Pareto efficient levels. Only the polluters pay the fees in a DR system. It requires little monitoring in firms' waste disposal behaviors because a refund provides firms with an economic incentive to return their waste materials.

A product charge scheme imposes a charge on the polluting input y_{3f} to provide the externality with a price. When a product charge is set equal to the marginal disutility generated by one unit of the polluting input (i.e., $u_e g_3$), a firm will face the full production costs on the polluting input. Therefore, a product charge has the same impact as a deposit, inducing firms to produce at efficient levels. This scheme might entice a firm to use substitute inputs incurring no charge. In the case of a product charge without a refund, a firm has no incentive to dispose of its waste properly and will fail to return waste at an efficient level. This implies that the benefit of an externality reduction ($-u_e$) from a return process will not be accounted for. Thus, the amount of waste return is not Pareto efficient. In this scheme, a product charge is placed on the sale of a polluting input regardless of the firm's waste disposal method. Those who return wastes to recycling centers lose out because they do not generate externality but still pay the charges.

A user fee is imposed on the amount of externality-generating wastes (s). This policy levies a direct, volume-sensitive charge for waste handling services in proportion to the waste generated. When the disposal behavior is detectable, a firm will be charged on the basis of its marginal disutility of the disposal method adopted. This will entice a firm to produce at efficient levels if the fee reflects the marginal damage cost generated from waste (i.e., u_e). A user fee serves as a disposal charge that induces firms to adopt a technology that generates less waste, or to employ a socially desirable disposal method. However, hazardous waste is classified as a non-point pollution, and thus the monitoring and enforcement costs are high. If the fee is based on the amount of waste disposal when the monitoring system is not perfect, firms may illegally dispose of their wastes to avoid the payment. Littering or illegal dumping is a potential side effect of the user fee system.

Another way to account for externalities is to charge firms a fine on their illegal dumping. Here, it is assumed that the return process is the only alternative to illegal dumping. A penalty is imposed when the occurrence of non-return has been detected. If the disposal behavior is perfectly detectable, a penalty is employed on non-return due to $e = s - \delta$. The efficient charge rate would be u_e per unit of non-return waste. If the monitoring system is not perfect, an efficient charge rate depends on the probability of non-return being detected. This situation will be discussed in section 3.3.4. If a penalty can reflect the shadow price of the externality, the production and waste return levels will be Pareto efficient. However, there is a drawback to this policy. When the wastes have a large or long-term effect, and the penalty is higher than a firm can afford, the firm might go out of business without paying the full amount of penalty, or, a firm may have already shut down when non-return has been detected. In these two cases, a fine cannot effectively control externalities because this ex-post punishment does not make firms face full production costs.

A recycling subsidy is paid directly to recyclers or producers for recycling waste materials. In this framework, a recycling subsidy is assumed to be paid on the return process. A profit-maximizing firm will return its waste product at the level where the marginal return cost equals the subsidy. If a subsidy equals the marginal disutility reduced from waste return ($-u_e$), Pareto efficient levels of waste return results. The first drawback of a subsidy is that, a firm has no incentive to generate less waste without a product charge or a user fee. In addition, a subsidy creates a burden to finance the budget. Taxpayers lose because they pay the costs of recycling.

A DR system as well as the penalty is a point-of-littering charge on externalities. A product charge can be regarded as a point-of-manufacture charge on inputs, or alternatively, as a point-of-purchase charge on the potential waste content of products. The user fee is a point-of-disposal charge on waste products, and the recycling subsidy is a point-of-manufacture subsidy on recycling processes.

A DR system satisfies an equality criteria that a product charge scheme does not: only polluters pay (the polluter-pays-principle or the PPP). The DR system also has an advantage over the user fee scheme. The DR system does not require perfect information of firms' disposal behavior, thereby the detection costs are low. Different from a penalty scheme, a DR system provides an ex-ante policy to control hazardous waste disposal. A DR system has two advantages over subsidies: enticing a firm to produce at an efficient level and balancing the budget within this scheme.

As for the distribution of policy costs, each charge scheme except a DR system has its drawbacks. A product charge ignores the return process, therefore producers who return their wastes become the losers. A user fee ignores illegal dumping behavior, thereby the losers are the public which is affected by externalities. Under a penalty, the producers who do not return their wastes and are not detected are the gainers. For a recycling subsidy, the costs are imposed on tax-payers. Within a DR system, the costs are placed on the producers who actually generate externalities. As for the reduction of externalities, a product charge only accounts for the production side, while a subsidy only accounts for the return process. A user fee and a penalty scheme are able to account for both side of externalities, but they are limited by the monitoring system. On the other hand, a DR system has desirable properties that requires less detection efforts as well as accounts for the efficient levels of production and waste return.

3.3.2 Balanced Governmental Budget Constraint

This section assumes that government collects deposits from a waste-generated input and distributes refunds to a waste return process. The levels of deposit and refund, which balance the governmental budget constraint when the government uses the surplus generated from a DR system to subsidize the deficit of a waste return process, are discussed. Imposing a balanced governmental budget constraint will result in a second-best optimal solution. This solution is widely employed when a return process incurs a deficit under marginal cost pricing and lump-sum transfer is infeasible. Marginal cost pricing will incur a deficit when the production technology exhibits non-convexity or increasing-return-to-scale (IRTS) (Laffont, 1988). Therefore, the optimal condition derived in section 3.2 is no longer valid. Imposing a balanced budget constraint is widely discussed within the literature of public sector pricing. In this paper, government is assumed to finance the firm's deficit by raising the same amount of surplus from a DR system, which would break even the amount of deposits and refunds.

The model developed in section 3.2 illustrates the first best optimum. There are some differences between first best optimum and second-best optimum. The first best optimum requires that the quantity of waste returned is set at the level where marginal benefit equals marginal cost. At this point, the social welfare is maximized. However, when the waste return process technology exhibits increasing-return-to-scale, which might be due to significant fixed costs and small marginal costs, marginal cost pricing will result in a deficit to a firm. To show the budget of a waste return process, we should re-examine the model in section 3.2. Equation

(16): $r - \lambda_{2b} b_{\delta} = 0$, where the marginal cost of waste return equals the refund rate, determines the amount of waste return. Only interior solutions are considered in section 3.2. When extending the first order condition to incorporate corner solutions, the optimal level a firm's waste return might yield a corner solution: the firm returns none of the waste material. This occurs when the waste return process is costly. A profit-maximizing firm will not return any waste unless the profit from a waste return process is positive, i.e., $r\delta + p_{1y} y_{1b} + p_{2y} y_{2b} \geq 0$ should be satisfied. Whether or not a society should undertake a waste return process depends on the net social benefit of the return process. If the marginal cost from waste return is always greater than the marginal benefit (or a refund), the Pareto efficient level of waste return should be zero. However, if the marginal cost equals marginal benefit of waste return, the average cost exceeds the average benefit but the total benefit from return is greater than total cost (such as graphs 1). This results from a non-convex technology or a significant fixed cost from the waste return process. The optimal quantity of waste return is at the stage of declining average cost. To give firms incentive to undertake a waste return process, a policy-maker may want to subsidize a waste return process by the difference between average revenue and the average cost of waste return. That can be done either by raising the refund rate or by reducing the prices of resources used for waste return. The source of the funding might come from raising the deposit rate or the excise taxes from some goods. A governmental balanced budget constraint upon a DR system is imposed in the model. Government chooses the rates of deposit and refund as instruments to maximize social welfare given that governmental budget is balanced.

The figure 3 shows a special case where social benefits are greater than social costs from a waste return process at the waste-returned level where marginal cost equals marginal benefit.

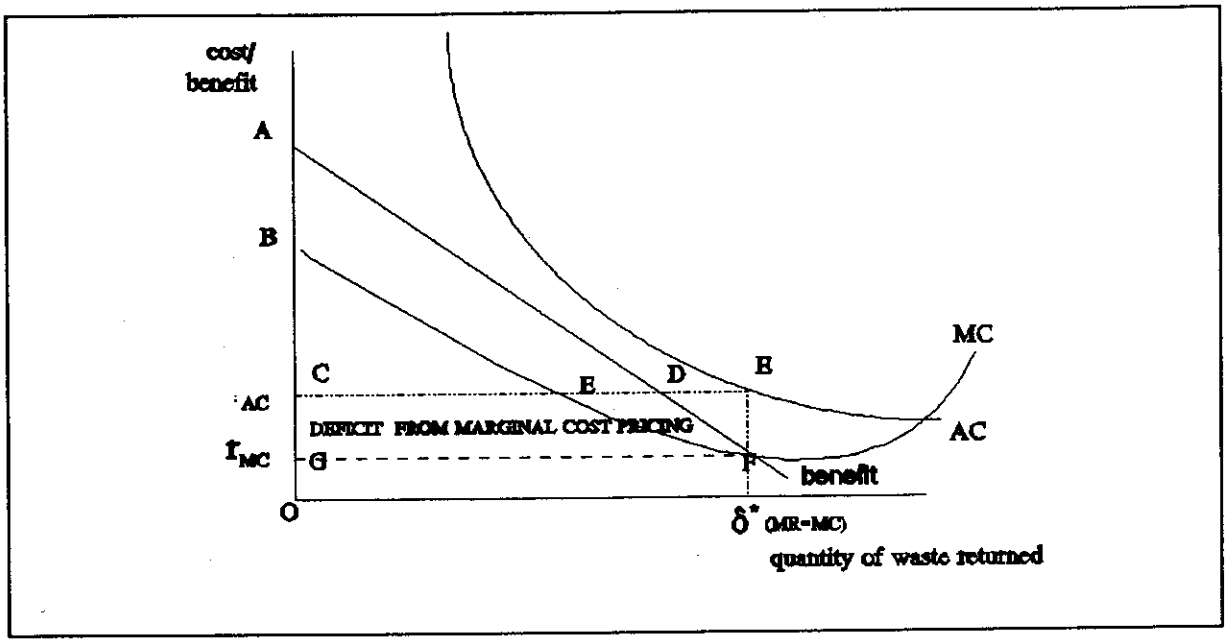

Figure 3 Deficit under marginal cost pricing.

According to marginal cost pricing, however, the firm will incur a deficit. As the figure 3 indicates, at the level where marginal benefit equals marginal cost for waste return, the total revenues ($r_{MC}\delta^*$) will not cover total costs ($AC*\delta^*$). In this cases, the social benefits from waste return (or consumer's surplus: the area of AGF) are greater than return costs (the area of GCEF) at the level of δ^* . In this case, there is no way for a private firm to maintain a balanced budget, although a waste return process will generate positive net social benefits. If a return process will incur a deficit, a private firm does not have any incentive to undertake waste return without any subsidy or compensation. In the event that the waste return process has net social benefit, society will be better off to have this process. This section examines how government finances the firm's deficit within a DR system while maintaining a governmental balanced budget.

In the world of first best optimality, lump-sum transfer is assumed to be feasible. Empirically, a lump-sum transfer is politically infeasible in most cases (Laffont, 1988, Varian,1992). One way to finance the deficit is by raising excise taxes. Unfortunately, taxes will incur dead-weight losses for society and have political difficulties in empirical application. From this consideration, imposing a balanced budget constraint becomes relevant, and will generate an outcome of second-best optimality. Within the first-best optimality, a lump-sum transfer (T) is made to compensate the deficit from waste return. That is,

$$T + r\delta + p_{1y}\, y_{1b} + p_{2y}\, y_{2b} = 0. \qquad (19.1)$$

The optimal conditions will not be affected but the endowment of the consumer will be reduced by the amount of **T**. When a lump-sum transfer is infeasible, the government might subsidize a return process subject to a balanced budget constraint. When the waste return is undertaken by the private sector, the profit (or deficit) for a return process is equal to $(r\delta + p_{1y}\, y_{1b} + p_{2y}\, y_{2b})$. Government is assumed to generate surplus ($-dy_{3f} - r\delta$) from a DR system to subsidize this firm. To maintain a balanced governmental budget constraint upon a DR system, the following condition should be incorporated into maximizing social welfare as well:

$$-dy_{3f} + p_{1y}\, y_{1b} + p_{2y}\, y_{2b} = 0. \qquad (19.2)$$

This constraint will also change the optimal conditions.

The method of solving this constraint problem is to examine the decentralized problem within the economy. The first step is to maximize the representative firm's profit with respect to its net outputs and waste return subject to technology constraints (given prices, endowment, deposit rate, and refund rate). π_0**(P,W,r,d)** denotes the amount of profits, where **P** denotes a vector of prices for these goods, **W** a vector of endowment, **d** a deposit rate, and **r** a refund rate. The firm then redistributes its profits to the representative consumer who maximizes his/her utility subject to his/her budget constraint. From these maximization procedures, an indirect utility function will be derived. The indirect utility is thus a function of prices, initial endowment, and profits, i.e., $\mathbf{V=V(P,W,r,d,\pi_o(P,W,r,d))}$. Government thus needs to choose optimal levels of deposit and refund to maximize the indirect utility function subject to governmental balanced budget constraint (Laffont, 1988). That is,

$$\text{Max } V(P,W,r,d,\pi_o(P,W,r,d))$$

$$\text{such that} \quad NR_{government} = NR(P,W,r,d) = -dy_{3f} + p_{1y}\, y_{1b} + p_{2y}\, y_{2b}=0. \tag{20}$$

The Lagrangian for this problem is

$$\begin{aligned} \mathscr{L} &= V(P,W,r,d,\pi_o(P,W,r,d)) + \gamma(-dy_{3f} + p_{1y}y_{1b} + p_{2y}\, y_{2b}) \\ &= V(P,W,r,d,\pi_o(P,W,r,d)) - \gamma\ (NR(P,W,r,d)), \end{aligned} \tag{21}$$

where γ is a Lagrangian multiplier. γ can be interpreted as the shadow price of imposing a governmental budget constraint. Utilizing the envelope theorem, the differential with respect to **d** and **r** will yield

$$V_d + \gamma\ [NR_d]=0 \tag{22.1}$$

$$V_r + \gamma\ [NR_r]=0. \tag{22.2}$$

The indirect utility function *V(.)* is assumed to be concave in π (risk-averse), while the corresponding marginal utility is positive but diminishing in π $(V_\pi>0$ and $V_{\pi\pi} <0$. *r* has a positive and *d* has a negative impact on profit function π [9] (i.e., $\pi_r>0$, $\pi_d<0$). The sign of NR_d is positive while NR_r is negative because increasing deposit rate raises government net revenue (NR) while increase refund rate decreases NR. Equation (22) indicates that due to the positive NR_d , V_d (marginal utility of deposit) will be at the stage of negatively sloped.

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[9]. Therefore, $V_r=V_\pi\pi_r>0$, $V_{rr}=V_{\pi\pi}(\pi_r)^2+V_\pi\pi_{rr}<0$, and $V_d=V_\pi\pi_d<0$, $V_{dd}=V_{\pi\pi}(\pi_d)^2+V_\pi\pi_{dd}<0$. That is, indirect utility function is both concave in r and d.

This implies that the deposit rate should increase. For the same reason, due to the negative value of NR_r , V_r will be at the stage of positively sloped (see Figure 4).

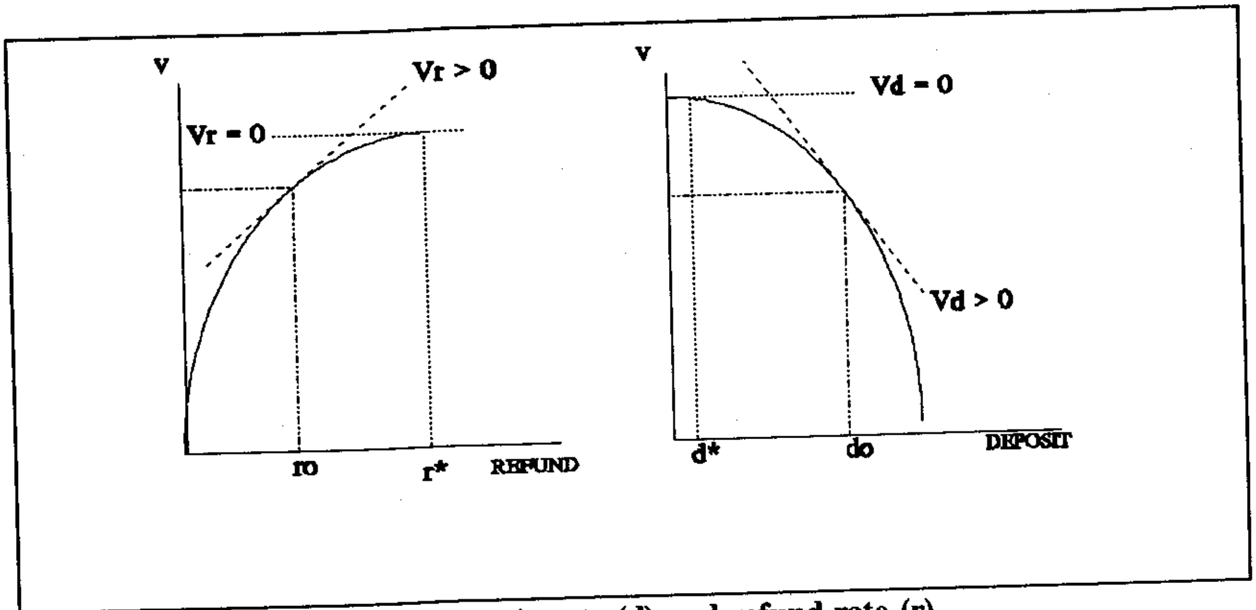

Figure 4 Indirect utility and deposit rate (d) and refund rate (r).

The implication is that the refund rate should decrease. These two results show that under the balanced budget constraint, the deposit rate should be greater and refund rates should be less than without the constraint. The higher deposit rate and lower refund rate raise governmental revenue. Therefore, the surplus will be sufficient to generate a second-best optimal result.

3.3.3 Combination of a DR System and a Penalty

Illegal dumping is a nonpoint pollution and detection of sources may be difficult and costly. Segerson (1988) discussed how to employ a penalty to control nonpoint pollution under uncertainty. In this section, a scheme of combining a penalty within a DR system is examined. For simplicity, it is assumed that any nonreturn waste will generate externality. Because the monitoring system is imperfect, the likelihood of a firm being penalized bases on the probability of non-return or illegal dumping behavior being detected. A deposit is assumed to be imposed on the purchase of a polluting input, and a refund is issued when a firm returns its wastes. In addition, a penalty is imposed when the non-return behavior is detected. This firm is assumed to be risk-neutral. Two issues are addressed: the impacts of a penalty within a DR system, and the efficient penalty within a DR system to control hazardous waste.

Due to imperfect monitoring, let $q(e)$ be the probability of non-return behavior being detected, and k be a fixed amount of penalty. The probability of incurring a penalty depends on the amount of externality generated by a polluting input (i.e. q depends on e *or* $s - \delta$). An externality has a positive impact on the probability of incurring a penalty (i.e. $q_e > 0$). When a firm reduces all externalities, the probability of incurring a penalty is zero. The more externalities a firm generates, the more likely it is that the firm will be penalized. If a firm does not return its wastes, the probability of being penalized is higher. The Lagrangian function of a profit-maximization firm within a DR system and a penalty scheme becomes:

$$\text{Max } \mathcal{L} = p_{1y} (y_{1f} + y_{1b}) + p_{2y} (y_{2f} + y_{2b}) + (p_{3y} + d) y_{3f} + r\delta - kq(g(y_{3f}) - \delta)) - \lambda_{1f} f(y_{1f} , y_{2f} , y_{3f} , g(y_{3f})) - \lambda_{2b} b(y_{1b} , y_{2b} , \delta); \tag{23}$$

$$\textit{where } q = q(e) = q (s - \delta) = q(g(y_{3f}) - \delta)$$

The associated profit-maximization conditions for the polluting input and waste return are:

$$p_{3y} + d - \lambda_{1f} (f_3 + f_s g_3) - kq_e g_3 = 0 \tag{24}$$

$$r - \lambda_{2b} b_\delta + kq_e = 0. \tag{25}$$

or,

$$p_{3y} + d - kq_e g_3 = \lambda_{1f} (f_3 + f_s g_3) \tag{24'}$$

$$r + kq_e = \lambda_{2b} b_\delta \tag{25'}$$

These equations provide the optimal combination of polluting input use and waste return under a deposit/refund scheme with a penalty. A penalty increases the marginal cost of the polluting input y_{3f}, so that the demand for this input will decrease, thereby reducing total output. On the other hand, a penalty increases the opportunity cost of non-return, thereby providing an incentive to return more waste.

To achieve Pareto efficiency, these two equations should be the same as equations (11') and (12') (i.e., the necessary conditions for Pareto efficiency). That is,

$$d - kq_e g_3 = u_e g_3 , \quad \text{or} \quad k = -[(u_e g_3 - d) / (q_e g_3)] \tag{26}$$

$$r + kq_e = -u_e , \quad \text{or} \quad r = -(u_e + kq_e) = - (d / g_3) \tag{27}$$

These equations yield the feasible combination for efficient levels of deposit, refund and penalty -- two equations with three policy variables. The amount of deposit, refund and penalty depend on the expected fine kq_e, as well as the marginal disutility of externalities $u_e g_3$. When d and r equal zero, the efficient penalty would be $(k = - u_e / q_e)$. When the marginal disutility from a waste-generating externality (u_e) is large, or the probability of being penalized (q_e) is small (due to the difficulty of illegal disposal detection), the efficient level of a penalty should be high. When the deposit or refund rate is higher, the Pareto efficiency requires that the fine should be smaller. An efficient penalty thus depends on the monitoring mechanism and the levels of deposit and refund.

When a DR system is operating at Pareto efficient levels, imposing a positive penalty becomes a distortion policy. Although a penalty can further reduce externalities, it costs society more resources than the value of externality reduction. That is, when the externality generated from a polluting input is charged at higher than efficient levels, output levels, as well as consumer surplus and producer surplus, are below efficient levels. Furthermore, a penalty will induce a higher return rate, but the marginal cost of return is greater than the marginal benefit of return. Neither result satisfies Pareto efficiency conditions.

As discussed in section 3.3.1, if a fine is levied when littering is detected, a firm may incur a negative profit. This firm might shut down without paying all costs. In this case, a penalty can not effectively control the externalities. On the other hand, a DR system is designed to account for the externalities that may happen in the future. That is, a DR system will entice a firm to consider future occurrence of externalities in order to reclaim its deposit[10]. Imposing a penalty will strengthen a DR system because it increases the cost of a polluting input and the opportunity cost of non-return. However, a Pareto efficient level of a penalty within a DR system should account for the costs as well.

The general equilibrium framework indicates that an efficient DR system should account for both benefits and costs of externalities. This framework also predicts that DR systems can entice a firm to produce and return waste at Pareto efficient levels. In some situations, DR systems are more likely than product charges, user fees, or penalties to induce safe disposal, and more than a subsidy to achieve a balanced budget and to produce at efficient levels. These advantages increase the feasibility of DR systems. Three empirical studies are referenced in the next section in a discussion of administrative costs associated with DR systems. Also discussed are the benefits and costs of implementing DR systems. These case studies are used to illustrate certain issues raised in implementing a DR system; e.g., who will bear the costs, who will gain the benefits, how to design a DR system, what are the administrative costs, and what are its

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[10] Performance bonds are one such application of DR systems which have been studied and recommended by Bohm (1981 & 1985), and Macauley, Bowes and Palmer (1992). By using these bonds, the problem of shutting down without paying the externality cost can be avoided.

strengths and weaknesses.

IV. THREE CASE STUDIES OF DEPOSIT-REFUND SYSTEMS

This section illustrates three case studies of DR systems. The objective is to relate these case studies to the theoretical framework developed in section III and examine the effectiveness of each specific DR system.

At the present time, most applications and analyses of deposit-refund systems have been limited to beverage containers. Porter (1978, 1983) led a study of Michigan's deposit-refund systems on beverage containers. This study addressed the issue of whether or not a DR system on beverage containers can potentially increase social welfare. In Porter's study, a benefit-cost analysis has been employed to examine the overall effects of DR systems.

Denny and McLaughlin (1985) and McLaughlin (1986) examined a DR system on pesticide containers in Maine. They outlined how a DR system is structured. Several obstacles in implementing this policy were also discussed in their studies. Furthermore, they examined the policy improvements and concluded a DR system has effectively reduced the litter of pesticide containers in Maine.

Several studies of waste oil management in West Germany were examined by Bohm (1981), OECD (1981), Opschoor and Vos (1989), and Piasecki and Davis (1987). The main feature of this policy was that a deposit and a refund were proposed for different production processes. A product charge served as a deposit on the purchase of fresh oil; a subsidy issued to waste oil recycling centers offering firms free collection services served as a refund. The refund rates were different depending on the recycling processes adopted. These studies discussed how a DR system was structured, and how refunds varied by different disposal methods. Several policies were also proposed to strengthen this DR system.

The following section will first examine the characteristics of each waste product and its related externalities, and then a review of the structure and implementation of DR systems would be presented. The evaluation of each scheme will focus on how a DR system effectively controls externalities in addition to the distribution of benefits and costs. What are the strengths and weaknesses of these case studies and how they influenced the results of the DR systems will be discussed as well. Finally, an extension of the theory to account for practical experience will be discussed.

4.1 MICHIGAN'S DEPOSIT-REFUND SYSTEMS ON BEVERAGE CONTAINERS

This case study employs a cost-benefit analysis to explore the benefits and costs of mandatory deposits of beverage containers in Michigan (Porter, 1978, 1983).

4.1.1 The Waste Product and the Nature of the Externality

Littering of empty beverage containers imposes an externality on society. The externality costs include collection costs, eyesore costs (aesthetic effects), and damage costs, such as the physical injuries to human beings or animals because of broken glass or can ring tabs. No reliable data are available for the external effects of littering. However, some valuation approaches such as contingent valuation (CV), averting expenditures, and clean-up costs can be conducted to estimate the environmental effects. The waste-generating process is directly related to the consumption of beverages. In the consumption process, a bottle of soft drink can be thought of as product y_{1f}. The purchase of a can of soft drink (y_{1f}) needs both drink content

(y_{2f}) and container (y_{3f} - polluting material). The empty container (y_{3f}) generates an externality on society if it is not properly disposed of. One unit of soft drink generates exactly one unit of waste ($g_3 = -1$).

4.1.2 Policy Design

In 1978, Michigan passed the "bottle bill" which required redeemable deposits on beverage containers. The objective of the Michigan deposit-refund system was to reduce the litter rate and hence to reduce these external effects substantially. The policy required a deposit of 10 cents/container, regardless of the size of containers. It is levied when beverages are sold. A refund equal to the deposit is issued when beverage containers are returned to retail stores. Each retail store serves as a collecting center of empty containers.

4.1.3 Evaluation of the Policy

Different from the framework developed in section III, the externality is generated from a consumption activity instead of from a production process. A DR system can reduce the externality while it also incurs some costs. An efficient deposit rate should be jointly determined by the marginal disutility as well as the marginal benefit of the externality of polluting input (from equation (15')). An efficient refund rate depends on the marginal disutility reduced and the marginal cost from waste return. A deposit of 10 cents imposed on a beverage container, increases the cost of consuming beverages and thus reduces the quantity demanded. In this case, the deposit rate is equal to the refund rate. To obtain a refund, a return process is undertaken that incurs some return costs. The amount of waste return depends on the refund rate and on the marginal cost of return. This return cost is related to people's valuation of time and to the cost of stockpiling containers.

Porter cited Syrek's study (1980) that showed the return rate was around 95%, and the beverage-related litter fell 85% in 1979. However, the prices of beverages in refillable bottles rose, and the quantities purchased fell. According to this study, in 1979, real Michigan beverage prices rose by 2-3 cents/container for soft drinks and 3-5 cents/container for beer. Consumption declined by approximately 106 million containers of soft drinks and 170 million containers of beer (Porter, 1983).

As for the distribution of costs and benefits from this DR system, five groups of people -- consumers, retailers, the public, scavengers, and producers -- are identified. First, consumers pay higher costs due to the increase in price and/or inconvenience of return processes. These costs can be calculated as the loss of consumers' surplus plus inconvenience costs of return. Porter illustrated the losses in Michigan beverage consumption due to mandatory deposits in Figure 5.

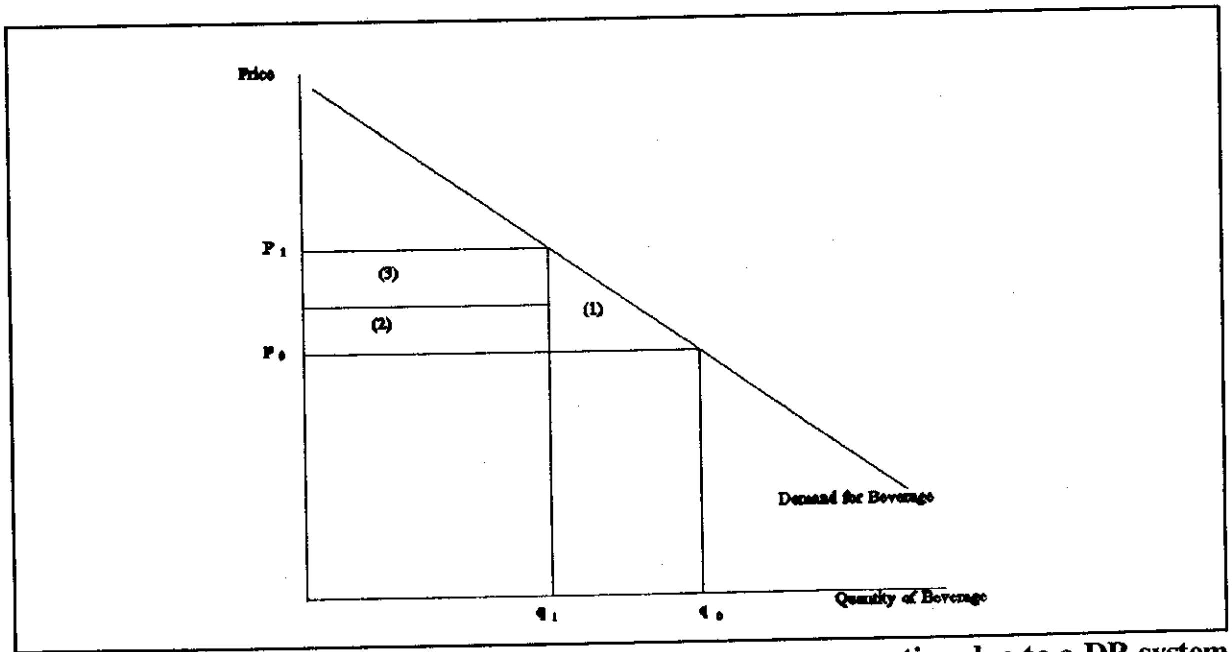

Figure 5 The losses of consumers in Michigan beverage consumption due to a DR system

In Figure 5, p_0 is the purchase cost per container of beverage before the enforcement of the bottle bill, and q_0 is the quantities consumed. p_1, and q_1 are the price and quantity of beverages after the bottle bill was implemented. The labelled area is the loss to consumers. It can be divided into three parts: (1) dead-weight loss due to the increase of beverage price; (2) the increase of beverage price; and (3) the inconvenience cost of returning bottles.

On the other hand, a DR system reduces consumers' solid waste disposal costs. The net benefits for consumers can thus be calculated by deducting the losses from the gains of waste disposal saving.

As for the retailers, a DR system increases the costs of handling, storage, transportation, sorting, and time that in turn lead to a reduction in the profits for retailers. As for the public, the policy increases benefits of reducing litter. Due to the refund, it becomes profitable for scavengers to pick up littering containers and return them to container-collection centers. As a result, more externality reduction is expected. As for the producers, a DR system reduces the cost of containers due to an increased use of refillable bottles, but because of the drop in sales, the producer surplus could increase or decrease.

Porter evaluated Michigan's DR system on the basis of the overall effects to examine whether the society can achieve potential Pareto improvement (PPI), that is, whether the total benefits of implementing a DR system outweigh the costs. In his study, the effects on scavengers are ignored. Porter assessed the benefits and the costs of a deposit-refund system by dividing the principal effects of a mandatory deposit policy on beverage containers into five categories. These effects are summarized in Table II.

From Table II, the benefits and costs are calculated based on two categories: dollars/per person and cents/container. This expression makes it convenient to compare the welfare change

Table II. Benefits (+) and Costs (-) of Mandatory Deposits (1979)[1]

Category (Source)	dollars/ per person	cents/ per container
1. Litter/pickup and disposal costs saved	+2.39	+.55
2. Amenity benefits of litter reduction[2]	+x	+0.23x
3. Consumers surplus lost due to price rises	-0.74 to -1.27	-0.17 to -0.29
4. Increase in resource costs of beverage delivery[3]	-12.87y to -19.39y	-2.95y to -4.44y
5. Consumer inconvenience cost incurred returning containers	-2.93 to -5.86	-0.67 to -1.34
Net effect	-1.28+x-12.87y -4.74+x-19.39y	-0.29+0.23x-2.95y -1.08+0.23x-4.44y

Note:(Source: Porter, 1983)

1. In 1979, the population in Michigan was 9.2 million and the quantity of beverages was 4.02 billion containers.
2. x is the consumers' average annual willingness to pay for 85% less beverage-related litter.
3. y is the fraction of the beverage price increases that represented cost increases.

based on per person or per container. The welfare gains consist of the reduction of litter pickup and disposal costs avoided (item 1), and the amenity benefits (item 2). The former is calculated by the costs saved from reducing the cleanup cost per mile by 13.2% and having less municipal solid waste (4.5% reduction in solid waste). The latter is based on the willingness to pay for 85% less beverage-container litter.

The welfare losses of a DR system can be derived from three categories: first is the consumers' surplus losses due to price rises calculated by changes on beverage quantity and price (item 3); second is the cost from the increase in resource costs of beverage delivery based on the change of producers' net profit (item 4); third is consumer inconvenience costs incurred from returning containers, estimated by the cost of stockpiling empty containers for period return (item 5). Item three is calculated based on the beverage consumption in 1979, where the quantity declined and the price rose in Michigan. The fourth category in Table II accounts for the fact that a DR system can decrease the costs of containers because these containers are refillable. But the container-cost savings of a refillable system could be offset by the increases in the costs of sorting, washing, inspecting bottles, and applying special labeling. In this study, Porter didn't calculate the fraction of price increases due to cost increases, because, he thought, this rise in beverage prices may not reflect real, enduring cost increases. As for the fifth item in Table II, Porter treated cost such as storage costs as a fixed cost ($3/year) that is independent of the number of containers involved. Because most containers are returned in the course of regular shopping, the return cost is very low.

Porter concluded that the overall effects of this program would depend on people's subjective valuation of the environment and on the fraction of the beverage price increases due to cost increases (y). If Michiganders place a high value on environmental amenities, their willingness to pay for 85% less beverage-related litter (x) would be high, and this raises the possibility of passing the benefit-cost analysis. For instance, if the fraction of the Michigan beverage price increases that represented cost increases (y) is zero, the marginal willingness to pay for 85% less beverage-related litter (x) is higher than $3. A DR system would potentially increase the total social welfare.

The strengths of a DR system in this case can be summarized by four factors. The first factor is convenience of container return. Porter cited Fisher's survey which reasoned that the return rates quickly rose due to easy returnability as the container-collection centers are located where people do regular shopping (Fisher, 1981). In addition, the uniformity of beverage containers makes the return process easier by reducing the return cost.

The second factor is large quantity with a high deposit/refund rate. A higher deposit/refund rate increases the opportunity cost of not returning the container, resulting in a higher return rate. The higher refund rate also increases the profitability for scavengers from the collection of littering containers. Compared to California's 1 or 2 cent deposit (which increased the return rate from 40% to 57%, Naughton, et al., 1990), the amount of deposit has a significant effect on the return rate. However, Table III shows a 10 cent deposit in Michigan has the same result as a 5 cent deposit in Maine, Vermont, and Oregon. Further research is necessary to determine whether a 10 cent deposit is too high.

Table III. Minimum Deposits and Average Return Rates in Mandatory Deposit States

State	Law Effective	Minimum Deposit Value ($)	Return Rates	Year of Return Rate Estimate
Oregon	1972	.02/.05	>90	1979
Vermont	1975	.05	>95	1976
Maine	1978	.05	90-95	1979
Michigan	1978	.05/.10	93	1986
Iowa	1979	.05	>89	1979
Connecticut	1980	.05	NA	-
Delaware	1982	.05	NA	-
Massachusetts	1983	.05	79	1987
California	1987	.02	57	1988
New York	1983	.05	77	1987

(Source: Naughton, et al., 1990. Journal of Consumer Affairs)

The third strength of a DR system is that it has low transaction costs, which includes return cost, handling cost, and administrative cost. These low costs, resulting from non-toxicity of containers that reduces storage cost and large quantity that reduces marginal return cost of each container, have made consumers and retailers more willing to coordinate efforts.

The fourth strength of the Michigan's DR systems on beverage containers is characterized by relatively low storage costs and return costs in Michigan: the costs of space and time are low in Michigan. Table III summarizes information on mandatory deposit systems in ten states. Some variation in results is found in this table. Generally, rural states such as Michigan, Vermont, Maine, and Oregon have higher return rates. The first reason might be attributed to a greater convenience of return. In these states, the population density is lower than in other states, so consumers as well as retail stores pay lower costs of empty container storage. The second reason is a lower opportunity cost of return because a large number of residents in these areas are farmers and their time cost estimates are lower. The third reason may be due to a higher aesthetic benefit from return (Naughton et al., 1990).

The first weakness of a DR system is the increase of handling costs for retailers. These costs affect the willingness of retailers to cooperate. Second, people who buy beverages from other states (without deposit) may ask for refunds. On the border regions, this problem occurs frequently (Sjolander, 1984). Issues in policy formulation include how to compensate retailers and prevent counterfeit claims for refund in implementing a DR system. Subsidizing collection processes, for example, can increase the benefit of handling returnable containers, and thereby increases the cooperation of these retailers.

4.1.4 Comments

The DR system from the Michigan case study confirms the results derived from the framework that reduces externality from littering. Porter's study also showed that a DR system increased the cost of beverage consumption and reduced the quantity demanded, leading to a reduction in consumer surplus. The characteristics of these recyclable containers that contributed to the success of this policy were, uniform size, large quantity, and non-hazardous storage. All of these factors have resulted in lowered return costs. These factors combined with a high refund rate resulted in a high return rate.

From the framework developed in section III, the benefits of a DR system lies in the welfare increases due to smaller externalities as the result of reduced output or waste return. The costs of a DR system depend on the welfare reduced either by decreased output or increased return costs. Porter's cost-benefit analysis is based on this concept. In addition to the costs accounted for in the framework, the social costs imposed by DR systems should be included in implementing DR systems, such as the sorting costs, storage costs, transportation costs, time, and other administrative costs.

In this case study, beverage containers are non-toxic. In extending the case study results to toxic wastes, the externality cost should account for the hazard caused by each waste material. A safe waste return process will enhance the cooperation of the polluting product users and the collection centers. Standardization simplifies the return process. The procedure of verifying counterfeit claims becomes important if many people ask for refunds without paying deposits. Increasing the cooperation of retailers is also critical to the implementation of a DR system. The following two cases will discuss more details about implementing a DR system to control hazardous wastes.

4.2 A DEPOSIT-REFUND SYSTEM ON PESTICIDE CONTAINER IN MAINE

This case study is based on two reports to the Maine Board of Pesticides Control on Maine's Returnable Pesticide Container Program (Denny and McLaughlin, 1985; Mclaughlin, 1986). It examines how a DR system is structured in controlling the empty pesticide containers.

4.2.1 The Waste Product and the Nature of the Externality

In 1981, pesticide containers were found in many open dump sites in Maine. These pesticide containers were expected to incur such externalities as soil, surface and ground water contamination. The externalities corresponding to the litter of used pesticide containers were generated from agricultural production processes. The physical damages could be estimated by laboratory and field tests. Then, the externality costs can be estimated from these damages. The main reason for empty container litter is that pesticide containers still have some toxic residual, resulting in the refusal of many landfills to accept these containers. Therefore, the options for proper disposal of pesticide containers are relatively few and are expensive. One unit of pesticide generates one unit of used container. A large pesticide container generates more externalities than a smaller one. Both powdered and liquid pesticides are substitute inputs and will generate hazardous waste.

4.2.2 Policy Design

In 1985, the Maine Board of Pesticides Control (MBPC) initiated a deposit-refund system on pesticide containers. The main purposes of this policy were to reduce externalities due to empty pesticide container littering, to improve solid waste management, to encourage material recycling and promote the use of refillable containers, to encourage rinsing of containers before disposal to increase the safety of these empty containers, and to encourage the use of the less toxic pesticides.

A DR system was imposed on liquid agricultural pesticide containers. The deposit was collected by dealers at the time of sale. For a container of less than a 30 gallon capacity, the deposit was \$5; for containers of 30 gallon capacity and over, the deposit was \$10 per container; and for refillable containers, dealers could collect a deposit greater than those required for non-refillable containers. To ensure safety, the containers were required to be triple rinsed and drained before return. Under MBPC's regulation, these containers could be returned to an authorized collection, disposal, or recycling facility specified by the dealer, or to the dealers' shops.

The policy required all containers specified under the act to have stickers that would identify the purchaser and the seller. The dealers were required to provide an affidavit containing information such as the name and address of the purchaser, the registered name of the pesticide, the number and size of each container, the serial number of the sticker affixed to each container, the amount of the deposit paid, the place where containers were to be returned for refund, and a space for the purchaser to sign certifying that the containers were properly rinsed according to the regulations.

As for the return process, the first step was to match the containers with the affidavits and to determine which containers were still being held by the purchaser. Next, the inspection staff identified these containers to make sure the rinsing procedure was being followed. When the inspection processes were complete, an MBPC form was affixed to the user's affidavit by the staff. In order to ensure safe return of the containers, dealers provided information on how to rinse bottles, and where to return them. If users disregarded the regulations, they could be fined up to \$500.

The policy specified three types of situations: in-state purchases, out-of state purchases, and on-hand containers. For in-state purchases, both dealers and purchasers were subject to the new regulations. For out-of-state purchases, only purchasers were required to register in MBPC. For on-hand containers, stickers were provided to farmers by MBPC without any charge.

From the outset, implementation of the policy encountered several obstacles. First, the dealers had several concerns: (1) they would be liable for potential spills, leaks, and contamination that might occur due to the storage of pesticide containers; (2) they feared that the public wouldn't tolerate empty container storage at a place of commercial business; (3) they needed storage space for empty pesticide containers; (4) they worried that the policy may strain dealer/customer relations. Furthermore, most municipal landfills refused to accept these returnable containers. Thus, most of the dealers were reluctant to cooperate. Later the staff of MBPC and the contractors began to organize sites by assuring people that the dangers were low and the process was beneficial. They also designed two specific times (mid-summer and late-summer) in a growing season to collect these containers.

Other initial problems included people missing the return date, high transportation costs for returning containers, and unavailability of convenient return sites. The first problem was solved by publishing the return dates in local newspapers a few days before the scheduled times. As for the second problem, can crushers were used to reduce the transportation costs. However, the available options to dispose of empty containers were still limited.

In the first year, most of the participants complained that the paperwork requirement was cumbersome. After some modification (that enabled dealers to simply record sticker numbers on purchasers' invoice at the time of sale.), the agents were more willing to cooperate with the program. The system was also modified to reduce the manpower requirement, such as decreasing the number of containers to be inspected and eliminating the mid-summer series of container inspections because of a low return rate during this time.

4.2.3 Evaluation of the Policy

Pesticides are employed as an input in agricultural production processes. The externality generated by empty pesticide containers provided farmers with an additional benefit when they did not pay the full disposal cost. The externality had a negative impact on social well-being. A DR system can control this type of externality. An efficient level of deposit or refund depends on the related marginal cost and marginal benefit as the framework and the first case study shows. $5 on small containers or $10 on large containers is the deposit rate. Because of the deposit, the cost of pesticides will increase. Several studies suggested that pesticide is a lumpy input where its value of marginal product is several times greater than its cost (Headley, 1968; Carrasco-Tauber and Moffitt, 1992). Thus, the quantity demanded might not be affected by this policy.

MBPC considered the DR system a success as most pesticide containers were properly rinsed and disposed of. In the 1985 growing season, 85% of containers (12,185) were returned to 34 inspection sites. Only 4% of these containers failed to meet MBPC's inspection requirements. After the implementation of a DR system, MBPC found that most pesticide users shifted their pesticide use from liquid to powdered formulation (Mclaughlin, 1986).

As for the distribution of benefits and cost, imposing a DR system on these containers increased the cost of pesticides and reduced farmers' profits. As for the impacts on consumers of agricultural products, because the demand for agricultural products are considered to be perfectly elastic[11], crop prices will not increase. Thus, the losers in this case are farmers and dealers. The costs are the sticker cost, return cost, cleaning cost, inspection cost, and administrative cost. The benefits are the reduction in externalities of pesticide-related waste.

There are two main strengths in this DR system. First is the use of affidavit. The affidavit provides two advantages: providing information of safety disposal and preventing counterfeit claims for refunds. Users failed to dispose properly in most cases because they didn't have enough information. This case reveals that full information was critical for the program to work well. In this policy, stickers provided useful information to pesticide users: how to rinse the bottles, and how, when, and where to return the bottles. The information of rinsing containers reduces the hazard of empty pesticide containers that ensures the safety of return processes.

Second, a larger container has a higher deposit rate. Because different sizes of containers have different impacts on generating externality, the deposit and refund rates were designed for different sizes, depending on the externality generated. A larger container is expected to produce more externality than is a smaller container, therefore raising the deposit rate.

There are three weaknesses within this DR system. One weakness is that pesticide users may shift their demand of refillable containers to non-refillable containers. The objective of a DR system was to encourage the return of refillable containers. Thus, this policy proposed to collect a greater deposit on refillable containers. However, given the same externality and return cost of these two containers, to encourage the use of refillable containers, it is more effective

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[11]. Maine is a small state such that the supply of agricultural products will not affect the market prices. For example, if the price of crop in Maine is higher than other states, other states will sell their products to Maine. As a result, the market of agricultural product can be thought of as an open economy.

to provide a higher refund with the same amount of deposit, or a lower deposit with the same amount of refund for refillable containers. The reason to provide a higher refund is due to higher reuse value of refillable containers.

The second weakness is that farmers substituted powder for liquid pesticides. This substitution effect should be accounted for in formulating a DR framework. If powdered pesticides have a lower externality than liquid formulation pesticides, this substitution effect is desirable. If these two types of pesticides generate the same amount of externality, a DR system should also be imposed on powdered pesticides, or a product charge imposed on powdered pesticides to reduce this substitution effect.

The third weakness comes from high administrative costs. It requires a great deal of manpower to inspect and verify the safety of a return process.

There is one impact which should be considered as well. According to this policy, containers should be triple rinsed before returned to collection centers. However, the residue from pesticide containers will contaminate groundwater when farmers rinse their bottles. This policy should also incorporate this impact.

4.2.4 Comments

Some externalities generated by used pesticide containers were reduced successfully when a DR system was employed. On the other hand, farmers' profits declined due to the purchase cost of pesticides increases. The deposit or refund rate for different container sizes is set differently according to the potential externality incurred. The administrative costs corresponding to this policy are the cost of affidavit, inconvenience of return, cleaning cost, and inspection cost and institution cost. Due to small quantity, toxicity and non-uniformity of pesticide containers, the administrative costs were relatively high in this case. A fine is expected to strengthen this DR system. To prevent the substitution effect, a product charge on non deposit-imposed pesticides are proposed.

From the framework developed in section III, the benefit associated with a DR system is the reduction of externalities by returning empty pesticide containers, while the costs are attributed to the decrease of agriculture profits as well as to the increase in return costs. The effectiveness of this policy depends on whether the total well-being increases. A cost-benefit analysis can be undertaken. The framework should be modified to account for the substitution effect. The costs of this DR system should extend to include the administrative costs as well. Moreover, the elasticity of demand for output should be considered to examine the distribution effect of a DR system.

4.3 WASTE OIL MANAGEMENT IN WEST GERMANY

The waste oil management in West Germany has been widely discussed in the literature (Bohm, 1981; OECD, 1981; Opschoor and Vos, 1989; and Piasecki & Davis, 1987). This study will illustrate how a DR system is structured to control waste oil.

4.3.1 The Waste Product and the Nature of the Externality

Improper disposal of waste oil imposes externalities on the environment. These externalities are generated by motor shops or by individual users. A great deal of oil reaches the ocean through waterways each year. This is expected to affect the water quality and has negative impacts on marine life. When oil is discharged to landfills, it contaminates groundwater, which may become a carcinogenic source. When it is incinerated without removal of contaminants, it affects air quality. If it is discharged to sewage systems, it increases treatment costs. The oil price in most countries is underpriced from a social point of view because it does not include externality costs and user costs. The externality cost is the damage cost caused by the use of oil, while the user costs are the shadow prices of current oil use. The user cost arises due to scarcity of oil that current oil use will reduce the amount of oil available for future use. In both cases, recycling processes become a desirable disposal method for waste oil. Failure to account for these costs will result in a lower recycling rate than is Pareto efficient. It has been estimated that 50 percent of lubrication oil is recyclable (Bohm, 1981).

4.3.2 Policy Design

To reduce the externalities imposed by waste oil disposal and to promote an increase in the recycling rate, Germany imposed charges on lubricant oil as a strategy to manage waste oil disposal. Since 1969 when a national waste oil law was implemented, charges on lubricants have provided supporting funds for the subsidization of waste oil recycling enterprises. Since 1969, manufacturers and importers paid a charge 75 DM per ton of fresh lubricant oil. Subsidy levels varied by the methods of processing waste oil. A subsidy of 120 DM per ton was paid for refining center; 102 DM per ton was paid for certain reprocessing, such as heating oils; and 100-126 DM per ton for incitation depending on the purification process used (Bohm, 1981). In 1989, the charge on fresh oil has risen to 200 DM per ton (Opschoor and Vos, 1989).

Under the national waste oil law, any mixture or emulsion containing at least 4% oil was subject to regulation. The Federal Office for Trade and Industry required recycling collectors to pick up all waste oil from sources producing quantities of 200 liters or more and required collectors to offer storage facilities for sources producing smaller quantities of waste oil. There was no collection charge for the contaminants below 12.5% of waste oil. Collection agencies could charge a fee for the collection of the remaining waste oil that contains higher levels of contamination. When waste oil was of high quality or when the price of fresh fuel oil was high, collection agencies could make payments to the waste oil producers.

4.3.3 Evaluation of the Policy

In this case, the deposit was a product charge on the purchase of fresh oil, and the refund was a subsidy to recycling centers to offer firms a cheaper disposal method. A DR system provided an incentive to firms to adopt a socially preferred disposal method. In the German case study, the marginal waste output is equal to one half (i.e. $g_3 = -0.5$). One half of all oil is consumed in the production process leaving the other one half to be properly disposed of. From the framework developed in section III, the refund rate in Germany should be twice higher than the deposit rate. An efficient DR system depends on the marginal user cost as well as the marginal damage cost. The charges (75 DM/per ton) paid on fresh lubricant oils purchased served as a deposit that increased the price of oil. The refund (100-126 DM/per ton) was in a form of free waste oil collection that would reduce firms' disposal costs.

In 1969, 92,000 tons of unrecycled waste oil were discarded. This amount fell to 5000 tons in 1981 with approximately 80% of all waste oil sold as waste (Opschoor and Vos, 1989). In 1983, 77.4% of the total amount of waste oil produced in Germany was picked up by authorized collectors. Most of the waste oil reaching recycling centers was either reprocessed into lubricants or burned as fuel in industrial facilities. Of the waste oil generated in 1983 only 0.1% was sent to landfills and 1.5% was dumped in unknown locations (Piasecki & Davis, 1987).

The distribution of benefits and cost in this deposit/refund system is influenced by the demand for oil, recycling costs, and administrative costs. From the framework developed in section III, it can be shown that a DR system will reduce externalities, thereby increasing social welfare. On the other hand, the price of oil may increase and then reduce the quantity demanded. If the demand for oil is considered to be inelastic and the purchase cost of oil increased, the demand for oil will not be affected but the consumers' surplus is expected to decrease. For producers who returned their waste oil before a DR system was imposed, they got a cheaper method of return under the DR system. Therefore, a DR system increases their profits. Otherwise, a DR system may reduce the profitability of firms. How a DR system affects demand for oil depends on its elasticity. If the demand for oil service is inelastic, consumers will bear all the costs of price increases. If the demand for oil service is elastic, there will be a reduction in oil services demanded. Both producer surplus and consumer surplus may decrease depending on the cost-sharing of the price increase. As for recyclers, subsidization increases the profit of recycling waste oil.

The DR systemre in Germany waste oil has three mains strengths. First, a high volume of collection produced an economical scale that lowered return costs. Second, the refund rates were differentiated on the basis of various waste oil disposal methods. The adoption of recycling method affected the amount of refunds received from the government and reflected the levels of externality-reduction by different methods. A DR system therefore provides firms with incentives to adopt a desirable disposal method. Third, a DR system has desirable effects in the long-run, such as reducing the non-recoverable percentage of oil, reducing the contamination of waste oil, and improving the treatment process (Bohm, 1981). In the framework, the marginal waste output of a polluting input will increase over time within a DR system, reducing the proportion of non-return waste materials.

One weakness under the scheme is that disposers of heavily contaminated oil should prefer disposing of waste oil in ways other than using pick-up collection services at a charge. Bohm suggested increasing the deposit and refund level to encourage the disposers of heavily contaminated oil to return the waste. He also suggested establishing gas station intermediaries to collect waste oil from small consumers.

Bohm proposed that record-keeping requirements on the purchase of fresh oil could increase the recycling rate. Furthermore, Opschoor and Vos (1989) suggested that the effectiveness of combining regulations with DR systems was high in promoting the return rate.

4.3.4 Comments

A DR system has resulted in a high recycling rate such that externalities of waste oil were reduced. A DR system may increase the price of oil and thus reduce producer surplus as well as consumer surplus, depending on the elasticity of demand. In this case, part of the oil is consumed in the production process so that the refund rate should be higher than the deposit rate. The attribute of non-uniformity in waste oil results in different refund rates. If the waste oil is less contaminated, recyclers pay a positive price to oil users to collect their waste oil. As a result, the recycling rate is higher for less contaminated waste oil. The residual value as well as the price of fresh oil has a positive effect on the return rate. When the price of oil is high, more waste oil is recycled. A large scale return process is employed because of lower costs of waste oil collection. Different disposal methods also have different refund rates. A DR system has a desirable result in promoting oil use technology in the long run. A record-keeping requirement, a regulation, or a product charge will strengthen this DR system.

From the framework developed in section III, the benefit associated with a DR system is the reduction of externalities by returning waste oils; while the cost is the increase in purchase price. In addition, this case study shows that the benefits should include the increase of recycled oil and the decrease of disposal costs, and the costs should include the administrative costs. The framework should be also modified to account for substitution effects.

V. ISSUES IN DESIGNING A DEPOSIT-REFUND SYSTEM

Combining the theoretical framework in section III and the case studies in section VI, this section examines how to design a DR system to control hazardous waste disposal. There are four issues to be addressed (Barthold, 1994): what is to be imposed; where in a production process to impose a DR system; how large the deposit and refund should be; and what alternative policies can be employed to implement a DR system.

The first issue regarding what is to be imposed depends on the characteristics of a polluting input. The theory reveals that, if the externality is related to the waste disposal of an input and a return process is important, a DR system can be considered. The three case studies presented, illustrate four situations where a DR system is desirable. First, products such as pesticides and waste oil have serious environmental problems attached to disposal. This policy can also be extended to other materials, such as mercury, solvents, planting, and cadmium, which generate toxic wastes and require proper disposal. Second, recycling and reuse are feasible and profitable to producers. Products with high residual values and the recycling processes that will not cause a large externality are grouped into this category. Waste oils, for example, have a high recycling value. Other materials such as solvents, refillable beverage containers, or some scrap materials, should also be included. In each case, a return of used products to collection or storage sites is profitable. Third, the volume of wastes is large and the proof of compliance is simplified such that retailers and users are willing to cooperate. In the case of beverage containers, the return rate is high because the return process is simple. In the case of the pesticide container return program in Maine, the improvement of the monitoring process increased the cooperation of farmers because this modification reduced return costs. Waste possessing the characteristic of uniformity is more likely to have lower monitoring costs. Fourth, transaction cost is low. Such factors as safe or non-toxic return processes, easily identifiable products, and an easily accessible waste collection center, will lower administrative costs.

In order to address the second issue of at what stages in a production process to impose a DR system, the life-cycle of a waste-generating product is shown to examine the sources of waste. In general, each material has a similar life-cycle as follows (Macauley, et al., 1992):

---> **Export**
Feedstock --> **Extraction** --> **Production** --> **Distribution** --> **Consumption** ---> **Home** (waste)
Imports (waste) ---> **Workplace** (waste)

There are several sources of waste-generation. In most situations, waste is generated from primary production and final consumption. An effective DR system will provide an incentive for a decision-maker to reduce the potential externality by reducing the use of the polluting input, and returning or recycling the waste generated for a refund. A DR system is imposed at the stage of the process before the externality is generated. For example, in the case of empty pesticide containers, a DR system is imposed on the purchase of pesticides in order to entice farmers to dispose of used pesticide containers properly. The DR systems are imposed on the consumers during purchase of both beverage and pesticide containers. In the waste oil disposal case, a deposit and a refund are imposed on the users and recyclers respectively. Thus, a deposit is imposed on the person who will generate waste, but a refund can either be issued to the users who return the waste or issued to the recyclers who can provide more efficient disposal methods to the users.

From the framework, the efficient levels of deposit and refund are determined by the impacts of externalities generated as well as by production and return technologies. A deposit should balance the benefits and costs of externalities from a polluting input, while a refund balances the benefits and costs of the return process. Information provided by a social utility function, a production process, a waste-generating process, and a return process is required. The measurement of an externality can be based on the subjective evaluation of consumers' willingness to pay, or can be based on objective scientific knowledge. An efficient deposit rate depends on the marginal waste output and the potential marginal disutility caused by the polluting input. From the three case studies presented, the size and toxicity of a waste product affect the amount of the deposit. The return rate is determined by the refund and the nature of return process. An efficient refund rate depends on the reduction of marginal disutility from waste return. The waste oil case indicates that a refund of waste varies by the disposal process adopted and by the residual value.

As for the fourth issue, several policies may strengthen a DR system. Examples of these include a ban or a product charge on non-returnable products which are substitutes for a DR-imposed product. A fine can be adopted if users employ alternative strategies that generate externalities. Labelling requirements on the product provides users the necessary information about methods and locations of return, and about amounts which can be refunded. In addition, a transaction record can prevent counterfeit for refunds and aid in the detection of illegal dumping. Supporting policies such as standardization also enhances the effectiveness of a DR system.

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

DR systems can efficiently control waste-generating externalities. In the short-run, externalities can be reduced by a DR system either by reducing the use of the polluting input or by returning the waste to a recycling center. In the long-run, a DR system can improve production technology by using less polluting inputs or reducing return costs.

The advantages of a DR system can be analyzed from various perspectives. First, from a waste disposal perspective, a DR system can reduce the waste stream either by using fewer waste-generating materials or by recycling. It also increases the efficiency of disposal by sorting waste. As a result, smaller externalities will be incurred. From a production perspective, a DR system encourages firms to produce at Pareto efficient levels and promotes advances in technology. From an administrative perspective, a DR system needs minimal governmental intervention because an efficient deposit rate or a refund rate will provide firms the economic incentives to achieve those levels of output at which social welfare is maximized. A self-supporting characteristic, that avoids an undesirable redistribution effect, is also an attractive feature for a DR system. A DR system provides an incentive to scavengers, leading to a reduction in external effects on the environment. From a dynamic perspective, within a DR system, firms have incentives to adopt more advanced production and return technologies which generate less externalities. The deposit and refund rates are also flexible to adjust with respect to inflation, to reflect the real externality costs (such as the case study of waste oil management in West Germany).

In conclusion, DR systems are considered environmentally effective because the externality can be reduced explicitly. By providing economic incentives, DR systems are administratively efficient and practical. DR systems are particularly consistent with "polluter-pays-principle (PPP)" (Opschoor and Vos,1989; Cropper and Oates,1992). All these considerations are desirable effects of imposing DR systems to control hazardous waste disposal.

There are two disadvantages of a DR system. First, transaction costs increase when a DR system is employed. These costs, such as identification, coordination, administrative, handling, sorting, time, and transportation, should be included when a DR refund system is impletemented. Second, it creates an incentive to claim a refund without paying a deposit.

Implementation of a DR system should balance all of the advantages and the disadvantages. A DR system is effective for waste materials that are uniform, large in quantity, and non-hazardous in storage. Other factors, such as low return cost, feasible return procedure, and safety regarding returns also affect the success of a DR system. Among these factors, safety is especially important because a hazardous return process incurs externalities as well. A DR system accompanied with regulations, a fine, or a product charge will strengthen the result. Standardization of a product, safety and convenience of the return procedure, a sticker to prevent counterfeiting, and compensating the retailers are instrumental to the implementation of a DR system.

A general equilibrium framework can aid in determining the efficient levels of deposit and refund. The relationship between the marginal social benefits and marginal social costs of using polluting inputs is illustrated within this framework. Moreover, this framework also examines the welfare change and the distribution of the benefits and the costs.

The framework developed in section III has simplified many factors. More realistic factors can be incorporated into the model for future research. First, the elasticity of demand should be incorporated into this framework to illustrate welfare change. Second, the production process can be modified to include alternative substitute inputs with different externality impacts. Third, externalities generated by return and by consumption could be incorporated. Fourth, the reuse or residual value of waste material should be considered as well. Also, the heterogeneity of wastes should be accounted for. Future research will be needed to include these elements into the analytical framework.

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