OPTIMAL MULTI-TIER REGULATION: AN APPLICATION TO MUNICIPAL SOLID WASTE

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CITATION AND REPRODUCTION

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Optimal Multi-Tier Regulation: An Application to Municipal Solid Waste

Peter S. Menell*

The traditional economic analysis of externality problems has, since the time of Pigou, viewed government intervention as an optimal taxation problem. The implicit nature of the externality and the model of the government are usually quite simple. Externalities are of the "end of the pipe" variety for which the government need merely impose an optimally determined tax. To the extent that administrative costs have been considered, the focus has been on how the Pigouvian tax should be altered in the presence of administrative costs (e.g., Polinsky and Shavell (1982).) There is some attention to alternative instruments — such as tradeable permits (e.g., Dales (1968)) — but the analysis typically has an either/or quality.

This traditional approach to the analysis of government intervention obscures important regulatory design problems encountered in addressing real world externalities. Many if not most externality problems are not of the simple "end of the pipe" varieties. Moreover, in most circumstances, there are multiple potential levels of government intervention, each with a different cost structure and set of technological and political constraints.

The externalities arising from the disposal of municipal solid waste highlights the limitations of the "end of the pipe" metaphor and the simple model of government intervention. The social costs of solid waste disposal depend on both the composition of the waste stream and the methods of disposal. The social cost of disposing plastic packaging, for example, varies significantly depending upon whether it winds up as on the ground as litter, in a waste-to-energy incinerator, a landfill, or a recycling plant. Government policy can affect the composition and the ultimate destination of the waste stream through a number of means. Solid waste can be regulated through raw material charges and standards, packaging charges, packaging bans, packaging standards, curbside charges,

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mandatory separation requirements, and deposit-refund systems, to name some of the major policies being considered by local, state, and federal legislatures and regulatory bodies.

This paper develops a model for analyzing the level and mode of municipal solid waste regulation. The distinctive features of the analysis are the modelling of the multi-tier structure of the externality and the multiple levels of potential government intervention. As background to the development of this richer economic model, the first section of the paper presents an overview of municipal solid waste regulation. The next section describes the model, analyzes the principal incentive effects of the range of regulatory policies, and compares the various policies in general and through the use of a simulation. The third section discusses the effects of administrative costs on the choice of an optimal policy. The fourth section discusses the generality and limitations of the analysis.

I. Overview of Municipal Solid Waste Regulation[1]

In order to develop a model for analyzing municipal solid waste (MSW) regulatory policies, we must have an understanding of the social cost structure of the MSW stream. This section first examines the characteristics of the MSW stream. It then looks at the various ways of recovering or disposing the end products of this stream. This section concludes with a brief summary of the policy instruments that have thus far been used in this area.

A. The Municipal Solid Waste Stream

The municipal solid waste stream comprises the complex process by which wastes move from raw materials to reuse, recovery, or disposal. Along the way, the stream is shaped by numerous manufacturer, consumer, waste processor, and municipal decisions. The waste stream begins with raw material and product design choices by manufacturers. These choices reflect consumer preferences for products and packaging, as well as design constraints and the cost of materials. Consumers influence the municipal solid waste stream both through their

[1] For an extensive background discussion, see Menell (1990).

purchasing decisions and, later, through their choices regarding disposal. Wastes that consumers reuse or compost do not reach the disposal end of the municipal solid waste stream. Wastes that consumers separate can be recycled; some valuable wastes that consumers do not separate, such as ferrous metals, can feasibly be separated for recycling after they reach a waste transfer station or disposal site. The remainder winds up in mixed refuse, which goes to a landfill or an incinerator.

Table I shows the total quantity and average composition of the MSW stream in the United States for 1986. On average, Americans discarded approximately 3.19 pounds of MSW per day. Table I also reflects the heterogeneous character of MSW. Most of the components, when separated, have significant salvage values. In addition, many wastes (particularly plastics, and to a lesser extent, rubber, textiles, wood, and paper products) have high energy contents, which can be extracted through modern incineration technologies. The components of the waste stream also vary widely in their volume[2] and bio- and photodegradability.[3] The components of the MSW stream also vary in their toxicity. Although most of the municipal waste stream is not toxic, a number of hazardous household materials, including batteries, inks, used oils, antifreeze, paints and paint solvents, insecticides, and herbicides, find their way into the municipal solid waste stream.

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[2] For example, plastics have significantly lower densities than the average density of landfilled materials, hence they take up significantly more volume for a given weight (U.S. EPA (1988) at A.C-11 - 12). Plastic products, however, tend to have much lower weight per container than other packaging materials (OTA (1989) at 100).

[3] Food and yard wastes degrade rapidly when exposed to high oxygen environments. By contrast, most plastics do not degrade in the presence of light and oxygen.

Although important with regard to littering, degradability is not a desirable attribute for most properly disposed of wastes. Recycled materials reenter the stream of commerce as useful products. Natural degradability can be undesirable to the extent it reduces recyclability. On the other hand, degradability is extremely desirable for composting. Incinerated wastes are largely destroyed through high temperature combustion. Therefore, non-biodegradability does not present an environmental problem, except to the extent it is related to the amount of residual ash. High moisture content, which is typical of many naturally degradable wastes, reduces the efficiency of incineration. And contrary to some perceptions, landfills are typically designed to slow or prevent degradation. (Menell (1990) at 662 n.25).

TABLE 1

Overview of the U.S. Municipal Solid Waste Stream*
(1986)

Materials	million tons	percent
Paper and Paperboard	50.1	35.6
Glass	11.8	8.4
Metals	12.6	8.9
Plastics	10.3	7.3
Rubber and Leather	3.9	2.8
Textiles	2.8	2.0
Wood	5.8	4.1
Food Wastes	12.5	8.9
Yard Wastes	28.3	20.1
Miscellaneous Inorganics	2.6	1.8
total	140.8	100**

* Wastes discarded after materials recovery (i.e., recycling) and before energy recovery.

** Total corrects for rounding error.

source: Franklin Associates (1988)

[TABLE 1]

B. Disposal and Resource Recovery Technologies

There are three principal means of waste disposal and resource recovery: landfilling, incineration, and recycling. Currently, the United States relies heavily upon landfilling, burying 83% of the municipal solid waste stream; approximately 6% of the waste stream is incinerated and 11% is recycled (Franklin Associates (1988.)[4] Due to regional and local differences in land use patterns, hydrogeological conditions, and other factors, the utilization of waste disposal and resource recovery technologies varies significantly across regions of the United States.[5]

Prior to the mid-1970's, most landfills in the United States were little more than open pits into which all types of wastes were deposited. In addition to creating noxious odors and aesthetic blight, this method of landfilling poses a serious risk to groundwater systems. Bio-degradation of wastes produces explosive gases that can accumulate and combust. Modern landfills reduce these risks through siting away from sensitive groundwater systems and the use of liners, leachate and gas collection systems, and monitoring equipment.

The social costs of disposing a particular material in a landfill include: collection and transportation; the general costs of building, operating, and closing a landfill; and the particular costs of disposing the particular material. Collection and transportation costs include the cost of vehicles and other equipment, labor, transfer stations, air pollution, noise, traffic congestion, and fuel. The general costs of a landfill include the costs of

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[4] By contrast, West Germany landfills 55%, incinerates 30%, and recycles 15% and Japan recycles 50%, incinerates 23%, and landfills only 27% (National Solid Wastes Management Association (1989)).

[5] Although approximately half of the states have almost no recycling (2% or less), seven states (Washington, Oregon, Delaware, Maine, Vermont, New Jersey, and Minnesota) recycle between 13% and 22% of their wastes. Similarly, while 20 states incinerate little or none of their wastes, Connecticut incinerates 66% of its waste and another six states incinerate 20% or more of their wastes. (Glenn & Riggle (1989).

siting, land acquisition, construction, operation, and closure, as well as such external costs as noxious odors and the risk of groundwater contamination. Many of these costs are largely independent of the characteristics of the type of material disposed. The ciritical factor is simply the amount of space that the material will occupy. Other costs, such as noxious odors, the risk of groundwater contamination, and closure costs (monitoring) depend upon the the characteristics of the particular material being disposed. For example, yard wastes, with their higher moisture content and degradability, might be more costly to dispose because they promote degradation, mixing of wastes, and leaching. Wastes containing toxic constituents or requiring more care in disposal will also have higher social disposal costs.

High temperature incineration serves as a means of both reducing the volume of solid waste and generating energy. This set of technologies can, depending upon the composition of solid wastes, reduce volume by 60-90% and generate significant amounts of industrial steam, electricity, and/or fuel. The efficiency of incineration facilities depends upon the design and operation of the incinerator and the composition of the wastes burned. Plastics have the highest energy content among the major components of the MSW stream; Inorganic wastes, such as glass and metals, and food and yard wastes have little or no heating value. Incineration, however, presents two significant environmental concerns: toxic air emissions and ash residues. These problems can be substantially reduced technologically, although the costs of control are significant.

The net social costs of incinerating a particular material include collection and transportation, the general costs of building and operating an incinerator, and the particular costs and energy benefits of incinerating the particular material and disposing any resulting ash. As with landfilling, some of these costs are independent of the material being processed or proportional to weight or volume rather than the specific characteristics of the material. Other factors, such as the energy revenues, level of toxic air pollutants, and amount and toxicity of ash residue, depend upon the specific characteristics of the material.

Recycling refers to the multitude of means of converting used products and packaging into useful raw materials and products. In 1986, the United States

recycled approximately 25% of aluminum, nearly 23% of paper, and 8.5% of glass wastes. No other components of the MSW stream were recycled at a rate greater than 5%.

Recycling generally consists of three distinct activities. Wastes must first be separated. Until a few years ago, consumers had to bring separated wastes to collection centers. In more than 1000 communities throughout the United States today, refuse removers collect one or a few separated items at the curbside. In a few communities, separation occurs at central transfer stations, landfills, or incineration plants. Waste processing is the second stage of recycling. Depending upon the type, quality, and purity of material, the processing required can range from simply sterilizing reusable containers to melting, shredding, or pulverizing the material and reconstituting new products, to wetting and turning biodegradable materials to produce compost. The third stage of recycling consists of locating or creating a market for recycled materials.

The social cost of recycling a particular material consists of the costs of separating, collecting, and transporting wastes and the salvage value (net of processing and marketing costs) of the resulting material or product. Collection and transportation costs for recycled materials are higher than for materials going to a landfill because of the additional time needed to pick up multiple categories of wastes and the greater travelling distances to recycling facilities. The net salvage value of recycled materials depends upon the costs of processing wastes, the costs of marketing recycled materials, and the value of such materials.

C. The Evolution of U.S. Municipal Solid Waste Regulatory Policy

Municipal solid waste regulation in the United States has traditionally been handled at the local level. Until the 1970's, most municipalities collected trash and deposited it in a town dump. The costs of collection, transportation, and dumping were (and in many cases still are) paid out of property taxes or other general tax revenues.

As a result of the vast expansion of federal environmental regulation in

the 1970's, the EPA now has extensive regulatory authority over municipal solid waste, particularly the design and operation of landfills and incinerators. These regulatory requirements have increased the actual cost of disposal, although their impact on the MSW stream is muted by the lack of marginal cost pricing of waste disposal in most communities.

A few states and a number local communities have implemented regulatory approaches that alter the marginal cost of waste generating activities. Disposal regulations seek to directly regulate consumers' disposal decisions. Many communities encourage or require households to separate up to three types of refuse for curbside collection. A few communities impose a per can or per bag charge for the collection of mixed refuse. Packaging regulations, such as excise charges and product bans, attempt to control the types of products that consumers purchase and the types of packaging that manufacturers offer. Deposit-refund systems combine elements of both packaging regulation and disposal regulation. They typically require the payment of a fixed fee for beverage containers, typically 5¢, which is refunded when the container is returned to a redemption center.

II. Optimal Multi-Tier Solid Waste Regulation with Zero Administrative Costs

This section develops a model of the MSW stream in which heterogenous consumers choose between two container types and decide whether to separate their empty containers. In order to isolate the principal incentive effects of the range of MSW policies, this section assumes that it is costless to implement the various policies. The next section of the paper analyzes the effects of administrative costs on the choice of policy.

This section first describes the economic model. It then characterizes the various policies in terms of the model and analyzes the principal incentive effects of these policies relative to the first-best allocation of resources. The final sub-sections compare the various policies in general and through the use of a simulation.

A. Description of the Model

The social cost of solid waste depends upon the quantity and composition of materials entering the MSW stream and the costs of recovering or disposing materials at the ends of the stream. The MSW stream is determined by three sectors of the economy: (1) production sector — which determines the design and types of products and packaging; (2) consumer sector — which makes purchasing and disposal choices (e.g., reuse, separation of recyclables, disposal with mixed refuse); and (3) disposal sector — which chooses disposal methods (e.g., recycling, landfilling, incineration).

1. Production Sector

In order to focus the analysis, the model is concerned with only one product, which we will refer to as sparkling water (X). The analysis assumes that sparkling water is competitively supplied, so that producers charge the marginal social cost of producing the product and its packaging. Sparkling water can be packaged in either liter-sized plastic containers (X_1) or liter-sized glass containers (X_2). The price of these products are P_1 and P_2 respectively. The weight of the containers are denoted by w_1 and w_2 respectively. Without loss of generality, the analysis assumes that $w_1 \leq w_2$.

2. Consumer Sector

For ease of exposition, the consumer sector is modelled as residential households, although the analysis would apply similarly to firms consuming products that generate wastes. Consumers make two important decisions which affect the solid waste stream: the type of container and whether to separate the container from mixed refuse. To focus the analysis on the composition of the MSW stream, it is assumed that all consumers purchase the same amount of sparkling water. Therefore, the purchasing decision is binary. The disposal decision is also binary: consumers either include their containers with their mixed refuse or, if the municipality picks up separated bottles, leave them in a separate bin at the curbside. If the municipality does not pick up separated trash at the curbside, consumers can also deliver separated containers to recycling centers, but this is more costly.

Consumers choose the packaging option and disposal method that yields them the highest net utility. For example, a consumer may prefer plastic packaging because of its lighter weight and greater resistance to breakage. Alternatively, she may value the clean taste of water from glass containers. The utility that a consumer derives from a container of sparkling water is equal to the satisfaction received from consuming the contents plus the satisfaction from the particular type of packaging less the cost of the product and any disposal costs that the consumer bears.

To simplify the analysis, the model assumes that each consumer receives the same level of utility from consuming sparkling water from a plastic container (U_o). The satisfaction from consuming water from a glass container is represented by $U_o + r$. r represents the extent (in cents per container) to which a consumer prefers glass to plastic. A consumer is of "type j" if her extra satisfaction from consuming glass is r^j. The model assumes that r is uniformly distributed between r_l ("low") and r_h ("high"). Since the consumer faces only two choices, a negative value for r^j means that the consumer prefers, <u>ceteris paribus</u>, plastic to glass containers.

In order to highlight the disposal decision and reflect the heterogeneity of consumers, the model assumes that consumers differ in their willingness to separate containers from other refuse. For example, environmentally conscious consumers might be willing to go to great lengths to ensure that a container is recycled, while others consider separating refuse to be a burden. In economic terms, consumers have different costs of separation — which includes the inconvenience of separation plus the costs of transporting wastes to the nearest collection point, either a recycling facility or, where the trash collectors pick-up recyclables, the curbside. Consumers separate containers when the benefit that they derive from doing so (including any financial benefit, e.g., from refunds, satisfaction from protecting the environment) exceeds their cost of separation.

The total cost of separating a container for a consumer of type k, TCS^k, equals a constant, d, plus a random variable, CS^k, which is uniformly distributed between CS_l ("low") and CS_h ("high"). The model assumes that the distribution of CS is independent of the distribution of r.

The constant d reflects whether or not the municipality picks up separated glass containers at the curbside: if the municipality collects recyclables at the curbside, then d equals zero; if not, then d equals a positive constant d_o. The value of d_o can be thought of as the base additional cost of transporting separated glass containers to a recycling center. Thus, if curbside collection of separated glass occurs and there are no disposal charges directly borne by consumers, then consumers of type k will separate their trash so long as CS^k is less than zero. If there is no curbside collection of separated glass, then only those consumers with CS^k less than $-d_o$ (plus any fee paid for returned bottles) will take separated glass to recycling centers.

3. Disposal Sector

A municipal authority (or its contractors) collects mixed refuse. Under some of the policies being compared, the municipality also collects separated containers at the curbside. Even if the municipal authority does not collect separated containers at the curbside, the consumer can bring separated containers to a recycling center.

The municipal authority (or its contractors) also disposes of mixed refuse and recycles separated containers. In order to focus upon purchasing and disposal incentives, the model assumes that the municipal authority uses the best disposal and recycling technologies available, i.e., those resulting in the lowest net social cost. The relevant social disposal costs are the marginal cost of disposing glass containers included in non-separated or mixed refuse (DC_2^n) (including collection, treatment, processing, and disposal), the marginal cost of disposing plastic containers included in mixed refuse (DC_1^n), the net salvage value of separated glass containers (DC_2^s) (market price of recycled glass less the costs of collecting and recycling separated glass), and the net salvage value of separated plastic containers (DC_1^s). It is possible that DC_1^s is negative, i.e., that the reuse value of a container exceeds the costs of collection, processing, and marketing. DC_1^s must be less than DC_1^n for recycling to be economically viable.

It is assumed that central separation of containers from mixed refuse is not cost-effective. The difficulty of central separation of mixed refuse is more readily apparent when a plethora of waste types are present and contamination of

materials can occur. A waste stream having these characteristics could be incorporated into our framework by introducing a random variable reflecting each household's amount of other mixed refuse. Rather than adding this extra layer of complication (which would not alter the results of the paper), it is better simply to view the present model as a comparative static exercise focusing on one waste component: sparkling water containers.

[TABLE 2]

B. Incentive Effects of Regulatory Policies

As a benchmark for the policy analysis, sub-section 1 derives the purchasing and disposal decisions and total social welfare for the first-best allocation of resources. As a second benchmark, subsection 2 derives the incentive effects for the status quo — i.e., consumers' marginal cost of disposing waste is zero and their purchasing and disposal decisions are not regulated in any other way. Subsection 3 characterizes and examines policies that regulate households' disposal decisions. The next subsection looks at policies that regulate consumer purchasing decisions. The final subsection analyzes multi-tier regulatory policies.

1. The First-Best Allocation of Resources

Total social welfare (SW) is defined as the sum of the utilities of the members of the society less the total social cost of disposing (or recycling) empty containers. The first-best allocation of resources is achieved when each consumer makes a purchasing decision and disposal decision that maximizes her or his contribution to total social welfare.

The optimal disposal decision can be derived by comparing the net social gain of separating refuse for a person of type k. The social gain from separating product X_i is ΔDC_i, while the social cost is CS^k.[6] Therefore, people of type k who purchase X_i should separate if:

[6] It is assumed that d = 0 for the derivation of the first-best, i.e., the municipality picks up separated refuse at the curbside.

TABLE 2

NOTATION

X_i	Product X packaged in material i: $i \in \{1, 2\}$
P_i	Price of product X_i
ΔP	$P_2 - P_1$
t_i	Additional retail charge for product X_i
Δt	$t_2 - t_1$
dr	Deposit charge and refund under traditional deposit-refund policy
DC_i^n	Social disposal cost of X_i if disposed in mixed refuse
DC_i^s	Social disposal cost of X_i if separated
ΔDC_i	$DC_i^n - DC_i^s$
ΔDC^s	$DC_2^s - DC_1^s$
ΔDC^n	$DC_2^n - DC_1^n$
U_0	Base level of utility from consuming X_1
r^j	Additional utility for consumer of type j from consuming X_2: $r \sim U[r_l, r_h]$
Δr	$r_h - r_l$
TCS^k	Total cost of separation for consumer of type k: $TCS^k = d + CS^k$
d	Fixed cost of separation: $d = \begin{cases} 0 \text{ if curbside collection} \\ d_0 \text{ if no curbside collection} \end{cases}$
d_0	Marginal cost of transporting containers central recycling center
CS^k	Cost of separation for consumer of type k: $CS \sim U[CS_l, CS_h]$
ΔCS	$CS_h - CS_l$
α	Proportional curbside charge rate for mixed refuse
v_i	Container volume of X_i; $v_i = 1$ liter $\forall$ i
w_i	Container weight of X_i; $w_2 > w_1$
Δw	$w_2 - w_1$
D	Density of distribution of consumers

$$CS^k \leq \Delta DC_1. \tag{1}$$

Assuming disposal decisions are made in this way, the net social welfare of a person of type (j, k) purchasing X_1 is:

$$U_o - P_1 - \min(CS^k + DC_1^s, DC_1^n).$$

The first two terms represent the net utility from consuming the product. The final term represents the social cost of disposal: either the cost of separation plus the social cost of recycling or the social cost of landfilling or incinerating X_1 as part of mixed refuse. Similarly, the net social welfare of a person of type (j, k) purchasing X_2 is:

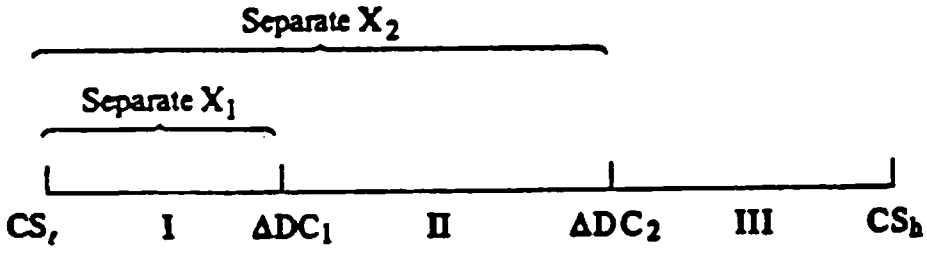
$$U_o + r^j - P_2 - \min(CS^k + DC_2^s, DC_2^n).$$

Given a first-best disposal decision (1), a person of type j should purchase X_2 if:

$$U_o + r^j - P_2 - \min(CS^k + DC_2^s, DC_2^n) > U_o - P_1 - \min(CS^k + DC_1^s, DC_1^n). \tag{2}$$

With consumers making disposal and purchasing decisions in this way, total social welfare of the first-best allocation of resources can be derived as follows. Figure 1 describes three relevant regions for the cost of separation.[7] All consumers with CS in region I separate their refuse. In region II, only consumers of X_2 separate. No consumers with CS in region III separate their refuse.

FIGURE 1



[7] Without loss of generality, it is assumed that $\Delta DC_1 \leq \Delta DC_2$. Figure 1 also assumes an interior solution, i.e., that $CS_l \leq \Delta DC_1$ and $CS_h \geq \Delta DC_2$.

Using equation (1), consumers in region I purchase X_2 if:

$$U_o+r^j-P_2-(CS^k+DC_2^s) > U_o-P_1-(CS^k+DC_1^s),$$

or equivalently, if:

$$r^j > \Delta P + \Delta DC^s.$$

Otherwise they purchase X_1. Similarly, in region II, consumers purchase X_2 if:

$$U_o+r^j-P_2-(CS^k+DC_2^s) > U_o-P_1-DC_1^n,$$

or equivalently, if:

$$r^j > \Delta P + CS^k + DC_2^s - DC_1^n.$$

Otherwise they purchase X_1. In region III, consumers purchase X_2 if:

$$U_o+r^j-P_2-DC_2^n > U_o-P_1-DC_2^n,$$

or equivalently, if:

$$r^j > \Delta P + \Delta DC^n.$$

When this inequality does not hold, consumers in region III purchase X_1.

For the purpose of calculating total social welfare, there are six regions of interest. In region IA, characterized by $CS^k < \Delta DC_1$ and $r^j \leq \Delta P + \Delta DC^s$, consumers purchase X_1 and separate their refuse. Therefore, these consumers' contribution to social welfare is:

$$W_1^s = U_o-P_1-(CS^k+DC_1^s).$$

In region IB, characterized by $CS^k < \Delta DC_1$ and $r^j > \Delta P + \Delta DC^s$, consumers purchase X_2 and separate their refuse. Therefore, these consumers' contribution to social welfare is:

$$W_2^s = U_o+r^j-P_2-(CS^k+DC_2^s).$$

In region IIA, characterized by $\Delta DC_1 \leq CS^k < \Delta DC_2$ and $r^j \leq \Delta P + CS^k + DC_2^s - DC_1^n$, consumers purchase X_1 and do not separate their refuse. Therefore, these consumers' contribution to social welfare is:

$$W_1^n = U_o-P_1-DC_1^n.$$

In region IIB, characterized by $\Delta DC_1 \leq CS^k < \Delta DC_2$ and $r^j > \Delta P + CS^k + DC_2^s - DC_1^n$, consumers purchase X_2 and separate their refuse. Therefore, these consumers' contribution to social welfare is W_2^s. In region IIIA, characterized by $CS^k \geq \Delta DC_2$ and $r^j \leq \Delta P + \Delta DC^n$, consumers purchase X_1 and do not separate their refuse. Therefore, these consumers' contribution to social welfare is W_1^n. In region IIIB, characterized by $CS^k \geq \Delta DC_2$ and $r^j > \Delta P + \Delta DC^n$, consumers purchase X_2 and do not separate their refuse. Therefore, these consumers' contribution to social welfare is:

$$W_2^n = U_o+r^j-P_2-DC_2^n.$$

Given these social welfare increments and assuming an interior solution (i.e., $CS_l \le \Delta DC_1 \le \Delta DC_2 \le CS_h$, and $r_l \le \Delta P + \Delta DC^s$, $\Delta P + CS^k + DC_2^s - DC_1^n$, $\Delta P + \Delta DC^n \le r_h$), total social welfare for society under the first-best allocation of resources is:

$$
\begin{aligned}
SW = {} & D \int_{CS_l}^{\Delta DC_1} \frac{1}{\Delta CS} \left(\int_{r_l}^{\Delta P+\Delta DC^s} \frac{1}{\Delta r} W_1^s dr + \int_{\Delta P+\Delta DC^s+\Delta DC^s}^{r_h} \frac{1}{\Delta r} W_2^s dr \right) dCS \\
& + D \int_{\Delta DC_1}^{\Delta DC_2} \frac{1}{\Delta CS} \left(\int_{r_l}^{\Delta P+CS+DC_2^s-DC_1^n} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+CS+DC_2^s-DC_1^n}^{r_h} \frac{1}{\Delta r} W_2^s dr \right) dCS \\
& + D \int_{\Delta DC_2}^{CS_h} \frac{1}{\Delta CS} \left(\int_{r_l}^{\Delta P+\Delta DC^n} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+\Delta DC^n}^{r_h} \frac{1}{\Delta r} W_2^n dr \right) dCS.
\end{aligned}
\tag{3}
$$

2. Status Quo

In the absence of any regulatory policy or other mechanism for internalizing disposal costs, consumers separate only if $CS^k < d_o$,[8] regardless of whether they purchase X_1 or X_2. Within the region in which consumers separate, they purchase X_2 when:

$$U_o+r^j-P_2-CS^k-d_o > U_o-P_1-CS^k-d_o,$$

or equivalently if:

$$r^j > \Delta P.$$

Within the region in which consumers do not separate ($CS^k \ge d_o$), they purchase X_2 when:

$$U_o+r^j-P_2 > U_o-P_1,$$

or equivalently if:

$$r^j > \Delta P.$$

Clearly, the status quo creates weak incentives for separating recyclable containers. Consumers will separate only if the satisfaction that they derive from separating a container exceeds the cost of transporting it to a recycling

[8] We assume that there is no curbside collection of separated items. Equivalently, such items are mixed with unseparated wastes. Therefore, consumers must deliver their separated wastes to a recycling center in order to gain the satisfaction of knowing that their wastes are recycled.

center. Furthermore, the status quo provides no incentives for consumers to purchase containers with lower social disposal costs. Consumers make purchasing decisions solely on the basis of their relative preference for containers and the difference in production costs.

3. Curbside Policies

Within the context of the economic model described above, the MSW stream is altered by changing the relative prices faced by consumers at the curbside, in the form of disposal fees, or at the retail level. In terms of the traditional economic analysis of externalities, the most direct way of internalizing the external costs of waste disposal is by charging a fee at the point of disposal, the curbside in our model. This approach can take a number of forms depending upon the costs of implementation. We will consider three versions of this approach: (1) the perfect curbside charge; (2) the optimal proportional curbside charge; and (3) mandatory separation.

Perfect Curbside Charge Policy — Under the perfect curbside charge policy, the consumer is charged the full social cost of disposal of the refuse placed at the curbside. In essence, a trash collector carefully inspects each household's separated and mixed refuse and tallies the weekly trash bill based on actual marginal social disposal costs.

Proposition 1: The perfect curbside charge policy achieves the first-best allocation of resources.

proof: Under the perfect curbside charge policy, each consumer is charged the full social cost of their disposal decision, i.e., DC_1^s if they purchase X_1 and do separate, DC_1^n if they purchase X_1 and do not separate, DC_2^s if they purchase X_2 and do separate, DC_2^n if they purchase X_2 and do not separate. Therefore, a consumer of type k will separate X_1 if the cost to her of separating $(CS^k - DC_1^s)$ is less than the cost to her of not separating $(-DC_1^n)$. This criterion is identical to that under the first-best allocation of resources (see (1)).

With this incentive to separate, a consumer of type r^j will purchase X_2 if:
$U_o+r^j-P_2-\min(CS^k+DC_2^s,DC_2^n) > U_o-P_1-\min(CS^k+DC_1^s,DC_1^n)$,

which is equivalent to (2). With consumers motivated in this way, the social welfare function under the perfect curbside charge policy has the same six regions as the first-best allocation of resources. ∎

In a model with many types of refuse and separation options, the perfect curbside charge policy would be extremely expensive (not to mention extremely messy) to implement. Nonetheless, as the purest version of the Pigouvian tax, it provides a useful guidepost for studying the range of solid waste regulatory policies.

Optimal Proportional Curbside Charge Policy — A more feasible approach is to charge a fee for disposal proportional to one readily measurable parameter of refuse such as weight or volume. In order to encourage consumers to separate recyclable items, the proportional charge will be assessed for only the mixed refuse; specified categories of separated trash is collected for free at the curbside.

The optimal proportional curbside charge is the fee (i.e., cents per pound or volumetric measure of mixed refuse) that maximizes social welfare. In order to focus the analysis on the externality problem, it is assumed that the charge revenue is redistributed to members of the society by way of lump-sum subsidies.[9]

With consumers paying a curbside charge of α times the parameter w_i for unseparated refuse, consumers of type k separate X_i if:

$$CS^k < \alpha * w_i .$$

Therefore, a consumer of type (j, k) purchases X_2 if:

$$U_o + r^j - P_2 - \min(CS^k, \alpha * w_2) > U_o - P_1 - \min(CS^k, \alpha * w_1) . \qquad (3)$$

With consumers making disposal and purchasing decisions in this way, total social welfare can be derived as follows. Figure 2 describes three relevant regions for the cost of separation.[10] As with the derivation of the social welfare function for the first-best allocation of resources, all consumers with

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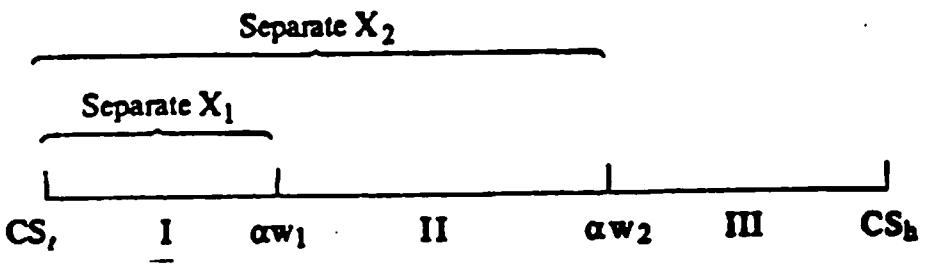
[9] This assumption is commonly made in the optimal tax literature (e.g., Laffont (1988) at 20; Sandmo (1975)).

[10] Figure 2 assumes an interior solution, i.e., that $CS_l \le \alpha * w_1 < \alpha * w_2 \le CS_h$.

CS in region I separate their refuse. In region II, only consumers of X_2 separate. No consumers with CS in region III separate their refuse.

FIGURE 2



Total social welfare under the proportional curbside charge policy is given by:

$$
\begin{aligned}
SW = {} & D\int_{CS_l}^{\alpha w_1} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P} \frac{1}{\Delta r} W_1^s dr + \int_{\Delta P}^{r_h} \frac{1}{\Delta r} W_2^s dr\right) dCS \\
& + D\int_{\alpha w_1}^{\alpha w_2} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+CS-\alpha w_1} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+CS-\alpha w_1}^{r_h} \frac{1}{\Delta r} W_2^s dr\right) dCS \\
& + D\int_{\alpha w_2}^{CS_h} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+\alpha\Delta w} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+\alpha\Delta w}^{r_h} \frac{1}{\Delta r} W_2^n dr\right) dCS.
\end{aligned}
\tag{4}
$$

Maximizing (4) with respect to the proportional curbside charge (α) yields a complex quadratic equation, which can be solved numerically for the optimal value of α.

Mandatory Separation — A third way to affect consumers' disposal behavior directly is to require separation of specific types of containers. Mandatory separation policies are applied to a few categories of refuse, most typically glass, newspaper, and aluminum. Therefore, we will assume that only glass containers are subject to mandatory separation. We will also assume that plastic containers are not collected at the curbside.

Assuming complete enforcement, consumers faced with a mandatory separation

policy of this type will always separate empty glass containers. Since consumers pay no direct disposal charge under this policy, their disposal cost for glass will be equal to their cost of separation. This policy imposes no disposal costs on consumers of plastic containers.

Under this mandatory separation policy, therefore, consumers will purchase glass containers only if:

$$r^j > \Delta P + CS^k - \min(0,\ CS^k + d_0).$$

This policy significantly distorts incentives relative to the first-best. Whenever the cost of separation for at least some consumers exceeds the social gains from separating glass, mandatory separation will over-encourage separation of glass containers. This excessive incentive to separate, in turn, will discourage the purchase of glass containers, resulting in excessive purchases of plastic containers.

4. Retail Policies

The relative prices faced by consumers can also be altered by imposing charges at the retail level. Unlike charging at the curbside, it is not possible to know at the time that the charge is levied what the actual social disposal cost will be. If the consumer separates the container from other refuse, then the social cost will be less than if she does not (assuming that $\Delta DC^{\bar{s}} > \Delta DC_i^s$). We will examine two types of retail policies: an optimal retail charge and a product ban.

Optimal Retail Charge Policy — In the absence of specific and reliable information on how a particular consumer will dispose of her refuse, the retail charge policy must be based on observable characteristics — actual purchasing behavior of the consumer and average disposal behavior of the community.

Proposition 2: The optimal retail charge for each container type is its expected disposal cost[11]:

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[11] We assume here that the municipality collects only mixed refuse at the curbside; therefore, consumers must bring separated containers to a central recycling center in order to derive utility from separating. If the municipality collects separated refuse at the curbside, the d_0 drops out of the formula for t_i. We also assume an interior solution, i.e., $CS_l \leq 0 \leq CS_h$.

$$t_i = \frac{(-d_0 - CS_l)}{\Delta CS} DC_i^s + \frac{(CS_h + d_0)}{\Delta CS} DC_i^n.$$

proof: Total social welfare under a retail charge policy is derived in the following way. Households with $CS^k < -d_0$ will bring separated containers to the central recycling center. Such households will prefer X_2 over X_1 when $r^j > \Delta P - \Delta t$. These households derive utility $W_1^s - d_0$. The remaining households that separate their containers derive utility $W_2^s - d_0$. Households that do not separate their containers also prefer X_2 over X_1 when $r^j > \Delta P - \Delta t$. These households derive utility W_1^n. The remaining households derive utility W_2^n. Therefore total social welfare under a retail charge policy is:

$$SW = D\int_{CS_l}^{-d_0} \frac{1}{\Delta CS}\left[\int_{r_l}^{\Delta P+\Delta t} \frac{1}{\Delta r}(W_1^s - d_0)\,dr + \int_{\Delta P+\Delta t}^{r_h} \frac{1}{\Delta r}(W_2^s - d_o)\,dr\right] dCS$$
$$+ D\int_{-d_0}^{CS_h} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+\Delta t} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+\Delta t}^{r_h} \frac{1}{\Delta r} W_2^n dr\right) dCS. \tag{5}$$

Maximizing (5) with respect to Δt yields the above optimal values for t_i's. ∎

Product Ban — Some jurisdictions have resorted to bans on specific packaging materials, most commonly plastic packaging, as a means of altering the MSW stream. A ban on plastic packaging can be seen, in economic terms, as an extreme retail product charge. The effective charge imposed by such a policy is slightly greater than each consumer's relative preference for the sparkling water packaged in plastic containers.

By dictating purchasing decisions, a ban on plastic packaging fails to provide proper purchasing incentives. Furthermore, by focusing solely on purchasing decisions, such a policy, like the optimal retail charge policy, provides no direct incentives for consumers to separate glass containers.

5. Multi-Tier Policies

A third set of policies alters relative prices at both the curbside and

retail levels. This might be desirable if one charge, by itself, fails to reflect the total social cost of disposal. For example, a curbside charge can often only be feasibly based on a single parameter (such as weight) even though multiple factors (such as weight, volume, compactability, degradability, and toxicity) affect social disposal costs. By monitoring both purchasing and disposal behavior, multi-tier policies elicit more complete information about consumers' purchasing and disposal decisions and therefore exact a better estimate of the social cost of such decisions.

Perfect Deposit-Refund Policy — A perfect deposit-refund scheme would impose a retail charge on all commodities equal to their disposal costs as part of mixed refuse (DC_1^n). A refund would then be calculated at the curbside for all separated materials. The refund would be equal to the difference between the social disposal costs of the items unseparated and separated (ΔDC_i). A consumer who chose not to separate would receive no refund. Whatever disposal decision the consumer made, therefore, she would bear the full social costs of that decision.

Proposition 3: The perfect deposit-refund policy achieves the first-best allocation of resources.

proof: Under the perfect deposit-refund policy, each consumer pays an additional charge of DC_1^n at the retail level and receive a refund of ΔDC_i if they separate their refuse. Therefore, a consumer of type k will separate X_i if the cost to her of separating ($CS^k + \Delta DC_i$) is less than the cost to her of not separating (0). This criterion is identical to that under the first-best allocation of resources (see (1)).

With this incentive to separate and the retail charge of DC_1^n, a consumer of type r^j will purchase X_2 if:

$$U_o+r^j-P_2-DC_2^n-\min(CS^k+\Delta DC_2,0) > U_o-P_1-DC_1^n-\min(CS^k+\Delta DC_1,0),$$

which reduces to:

$$U_o+r^j-P_2-\min(CS^k+DC_2^s,DC_2^n) > U_o-P_1-\min(CS^k+DC_1^s,DC_1^n),$$

which is equivalent to (2). With consumers motivated in this way, the social welfare function under the perfect curbside charge policy has the same six regions as the first-best allocation of resources. ∎

Optimal Multi-Tier Charge Policy — A more feasible multi-tier system would combine the optimal proportional curbside charge policy with the optimal retail charge policy. The optimal charges are similar to those derived under the straight optimal retail and proportional curbside charge policies, although are adjusted to take into consideration the effect of the additional level of regulation.

With consumers paying a curbside charge of α times the parameter w_i for unseparated refuse, consumers of type k separate X_i if:

$$CS^k < \alpha * w_i.$$

Therefore, given the retail charge of t_i, a consumer of type (j, k) purchases X_2 if:

$$U_o + r^j - P_2 - t_2 - \min(CS^k, \alpha * w_2) > U_o - P_1 - t_1 - \min(CS^k, \alpha * w_1).$$

With consumers making disposal and purchasing decisions in this way, total social welfare for the optimal multi-tier policy can be derived as follows. Figure 2 above describes three relevant regions for the cost of separation.[12] All consumers with CS in region I separate their refuse. In region II, only consumers of X_2 separate. No consumers with CS in region III separate their refuse. The optimal value of α, however, will differ from that derived under the optimal proportional curbside charge policy because of the interaction of the retail charge policy.

Assuming an interior solution, total social welfare under the multi-tier charge policy is given by:

$$\begin{aligned} SW = {} & D\int_{CS_l}^{\alpha w_1} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+\Delta t} \frac{1}{\Delta r} W_1^s dr + \int_{\Delta P+\Delta t}^{r_h} \frac{1}{\Delta r} W_2^s dr\right) dCS \\ & + D\int_{\alpha w_1}^{\alpha w_2} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+\Delta t+CS-\alpha w_1} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+\Delta t+CS-\alpha w_1}^{r_h} \frac{1}{\Delta r} W_2^s dr\right) dCS \\ & + D\int_{\alpha w_2}^{CS_h} \frac{1}{\Delta CS}\left(\int_{r_l}^{\Delta P+\Delta t+\alpha \Delta w} \frac{1}{\Delta r} W_1^n dr + \int_{\Delta P+\Delta t+\alpha \Delta w}^{r_h} \frac{1}{\Delta r} W_2^n dr\right) dCS. \end{aligned} \tag{6}$$

[12] Figure 2 assumes an interior solution, i.e., that $CS_l \le \alpha * w_1 < \alpha * w_2 \le CS_h$.

Maximizing (6) with respect to the proportional curbside charge (α) yields a complex cubic equation, which can be solved numerically for the optimal value of α.

Proposition 4: The optimal retail charge for each container type is its expected disposal cost[13]:

$$t_i = \frac{(-\alpha w_i - CS_l)}{\Delta CS} DC_i^s + \frac{(CS_h - \alpha w_i)}{\Delta CS} [DC_i^n - \alpha w_i] .$$

proof: Maximizing (6) with respect to Δt yields the above optimal value for t_i's. ∎

Proposition 5: If only one packaging type can feasibly be recycled — e.g., $\Delta DC_2 > 0$ and $\Delta DC_1 \leq 0$ — then the optimal multi-tier charge policy achieves the first-best allocation of resources.[14]

proof: By substituting $\alpha = \Delta DC_2/w_2$ into equation (6), it can be seen that total social welfare under the multi-tier charge policy is equivalent to that in (3) (adjusted to reflect the fact that consumers never separate X_1 and separate X_2 over the interval $[CS_1, \Delta DC_2]$. ∎

The intuition behind this proposition flows from the fact that the number of policy instruments is large enough to channel all consumer behavior toward efficient resource use. With three instruments (α, t_1, and t_2) and only three possible consumer choices (purchase glass/separate, purchase glass/mixed, purchase plastic/mixed), the optimal multi-tier charge policy is able to fully reflect the social cost of consumer purchasing and disposal decisions. This proposition, however, will not hold in a more general model in which there are more than two components of mixed refuse.

Traditional Deposit-Refund Policy — A third type of multi-tier system,

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[13] We assume here that the municipality collects separated refuse at the curbside.

[14] If one container-type is not recyclable, it seems reasonable to assume that consumers would not derive any psychic benefit from separating such containers. Moreover, the municipality would not collect such items separately at the curbside and the recycling center would not accept such containers.

currently in use in many parts of the United States, charges consumers a deposit fee (dr) at the time of purchase. This fee can be recovered by returning the empty container to a redemption location. The same deposit is usually charged for all containers. Consumers will separate either glass or plastic if their costs of separation are less than the refund, i.e., if $CS^k + d_o < dr$. Consumers will purchase glass if their relative preference for glass (r^j) exceeds the cost differential between glass and plastic (ΔP).

Unlike the perfect deposit-refund policy, the traditional deposit-refund policy does not replicate the first-best allocation of resources. This is because the deposit and refund amounts are not based directly upon social disposal costs. The constraint that deposit and refund amounts be the same prevents the traditional deposit-refund policy from providing correct incentives for disposal of particular containers. Moreover, because the deposit-refund amount is the same for both packaging types, the traditional deposit-refund policy has no net effect on <u>relative</u> purchase prices.[15] Furthermore, by requiring consumers to deliver separated containers to redemption centers rather than providing curbside pick-up, the traditional deposit-refund policy results in higher transportation and collection costs. Since the municipality must already collect unseparated refuse at the curbside, the traditional deposit-refund policy misses economies in collecting all separated items at the curbside. (Compare Porter (1978)).

C. Comparison of Regulatory Policies: General Results

<u>Proposition 6</u>: Each of the optimal charge policies dominate the status quo.

<u>proof</u>: The status quo is equivalent to the optimal retail charge policy with $t_i = 0$. Since t_i is chosen to maximize the social welfare function, it follows that total social welfare under the optimal retail charge policy is at least as high as under the status quo. The status quo is equivalent to the

[15] The use of different deposit-refund amounts for different container types (based on social disposal costs) alleviates, although does not in general fully remedy, this distortion.

optimal curbside charge policy with $\alpha = 0$ and $d > 0$. By the same logic, the optimal proportional curbside charge policy (and the optimal multi-tier policy) perform at least as well as the status quo. ∎

Proposition 7: The status quo dominates the mandatory separation policy, the product ban policy, and the traditional deposit-refund policy for some parameter values.

proof: When $\Delta DC_2 \approx 0$, $DC_2^n \approx DC_1^n$, $\Delta CS >> 0$, and $\Delta r >> 0$, the status quo will be less distortionary than mandatory separation of X_1. When $r_h < 0$, the status quo will be less distortionary than a product ban on X_1. When $dr >> d_0$ and $\Delta DC_i \approx 0 \ \forall \ i$, the status quo will be less distortionary than the traditional deposit-refund policy. ∎

Proposition 8: The optimal retail charge policy and the optimal multi-tier charge policy dominate the product ban policy.

proof: The effect of a product ban can always be achieved through the optimal retail charge policy and the optimal multi-tier charge policy through a suitably high retail charge on the banned product. Therefore these policies will always perform at least as well as the product ban. ∎

Proposition 9: It is not possible to prove that the optimal proportional curbside charge policy dominates the product ban in general.

proof: The social cost of disposing one type of container may be so large that none should be sold. Since the optimal proportional curbside charge policy does not directly regulate the purchase of containers, there will be parameter values such that the product ban is more efficient than the optimal proportional curbside charge policy. ∎

It should be noted that the parameter values for which Proposition 9 hold are extremely unlikely in the context of MSW policy. Since solid waste, as opposed to hazardous waste, concerns non-toxic or low toxicity materials, it is difficult to imagine cases in which one packaging type is so undesirable as to make a product ban superior to an optimal proportional curbside charge. The one example that comes to mind is the use of CFCs in packaging. The external effects

of CFCs, most importantly the depletion of the Earth's protective layer of ozone, may justify a product ban. On the other hand, an optimal retail charge would prove at least as effective as a product ban (assuming, of course, that administrative costs are comparable).

Proposition 10: The optimal multi-tier charge policy and the optimal proportional curbside charge policy dominate the traditional deposit-refund policy.

proof: The traditional deposit-refund policy constrains the deposit to equal the refund. In addition, the specific charge is only roughly (if at all) based on net salvage values. The optimal proportional curbside and multi-tier charge policies can perform at least as well as the traditional deposit-refund policy by using a curbside charge based on volume that would be equal to the refund. Since the traditional deposit-refund policy requires households to incur greater costs in separating waste by utilizing redemption centers rather than curbside pick-up, it will be less efficient than either of the optimal proportional curbside and multi-tier charge policies. ∎

Proposition 11: It is not possible to prove that the optimal retail charge policy dominates the traditional deposit-refund policy in general.

proof: Since the optimal retail charge policy does not have any direct effect on the incentive to separate waste, the traditional deposit-refund policy can, for some parameter values, achieve a more efficient allocation of resources. ∎

Proposition 12: It is not possible to prove that the optimal charge policies dominate the mandatory separation policy in general.

proof: The mandatory separation policy can effectively achieve complete separation of one container type and no separation of the other type. The optimal retail charge policy does not have any direct effect on the incentive to separate waste. The optimal proportional curbside and multi-tier charge policies cannot achieve this level of discrimination in separation activity because the charge is based on the weight or volume of mixed refuse generally. Therefore, for parameter values reflecting sufficiently high salvage values for one

container-type and negative salvage values for the other, the mandatory separation policy can be most efficient, despite its distorted purchasing incentives. ∎

D. An Illustrative Simulation

In order to obtain a more complete ranking of the various policies, it is necessary to make some plausible assumptions about the parameters of the model.[16] We assume that the production costs for glass and plastic one liter bottles of sparkling water are the same, 80¢. Each consumer derives the same level of satisfaction from consuming the sparkling water (U_0 = 95¢). Consumers' relative preference for container type (r) is distributed uniformly between -5¢ and 5¢. With regard to separating containers with significant net salvage values, the most environmentally conscious consumers are willing to separate even if it costs them 3¢ (in travel cost and/or storage space) per container. The most slovenly (or incapacitated) would be willing to pay 5¢ to avoid the burden of separating. Consumers are distributed uniformly between these extremes. We further assume that bringing empty containers to a recycling center costs each consumer 2¢ per container in travel expenses and additional inconvenience. Using the rough estimates of disposal costs based on collection cost estimates, tipping fees, and recycling spot prices, we assume the following social disposal costs: 3¢ for non-separated plastic (DC_1^n); 2¢ for non-separated glass (DC_2^n); the net salvage value of .5¢ for separated glass (DC_2^s); and plastics recycling is not economically viable (DC_1^s > 3¢).[17] For computing the optimal proportional

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[16] These parameter values are based on the limited hard data available (such as collection costs, tipping fees, salvage values) and casual empiricism (e.g., grocery store prices). The purpose here is principally illustrative. A sensitivity analysis of this illustration is discussed in Menell (1990) at 704.

[17] According to OECD (1981), collection represents 50 to 65 percent of total disposal cost, transport represents 3 to 15 percent, and treatment (including landfilling) represents 20 to 40 percent. Given the extraordinary increase in "treatment" costs since this report was prepared, owing to the rapid depletion of available landfill and concerns about landfill safety and the risks of incineration, treatment is likely to be a much more substantial part of total disposal costs today. Disposal costs range from as low as $3.15 per ton in Boise, Idaho (landfill tipping fee in 1987) to as high as $110 per ton in the Northeast. (Menell (1990) at 665 - 66). In constructing our range of disposal costs, we also consider the fact that plastic containers, though lighter than

curbside charge (α) based on weight of unseparated refuse, we assume weights for plastic and glass containers of .3 pounds and 1 pound per liter container, respectively. We assume equal volumes for computing the optimal proportional curbside charge based on volume of mixed refuse.

Figure 3 shows the incentives to separate glass under each policy for these parameter values. Given a disposal cost of 2 cents per unseparated glass container and a net salvage value of .5 cents per separated glass container, consumers with costs of separation less than or equal to 2.5 cents should separate. As demonstrated above, the perfect curbside charge, perfect deposit-refund, and optimal multi-tier charge policies produce these incentives. The optimal proportional curbside charge policy (using weight or volume) comes relatively close to the first-best incentives — slightly too little separation under the weight measure (α = 2.4¢) and too much separation under the volume measure (α = 3¢). The traditional deposit-refund policy also performs well under these parameter values. This reflects the coincidence that the difference between the deposit charge (5¢) and the fixed cost of transporting separated items to a recycling center (2¢) is close to the social gain of recycling (2.5¢). With the cost of separation of the least inclined group at 5¢, the mandatory separation policy leads to excessive separation of glass — glass purchasers with costs of separation between 2.5¢ and 5¢ will separate, even though the gain to society (2.5¢) is less than their cost of separation. On the other hand, the optimal retail charge, the product ban, and the status quo yield much too little separation of glass containers.

[FIGURE 3]

Turning to the purchasing incentives, Figure 4 graphs the critical values for consumers' subjective preferences for packaging (r^j), i.e., the level below which consumers purchase plastic and above which they choose glass, over the range of costs of separation under each of the policies. The critical values for

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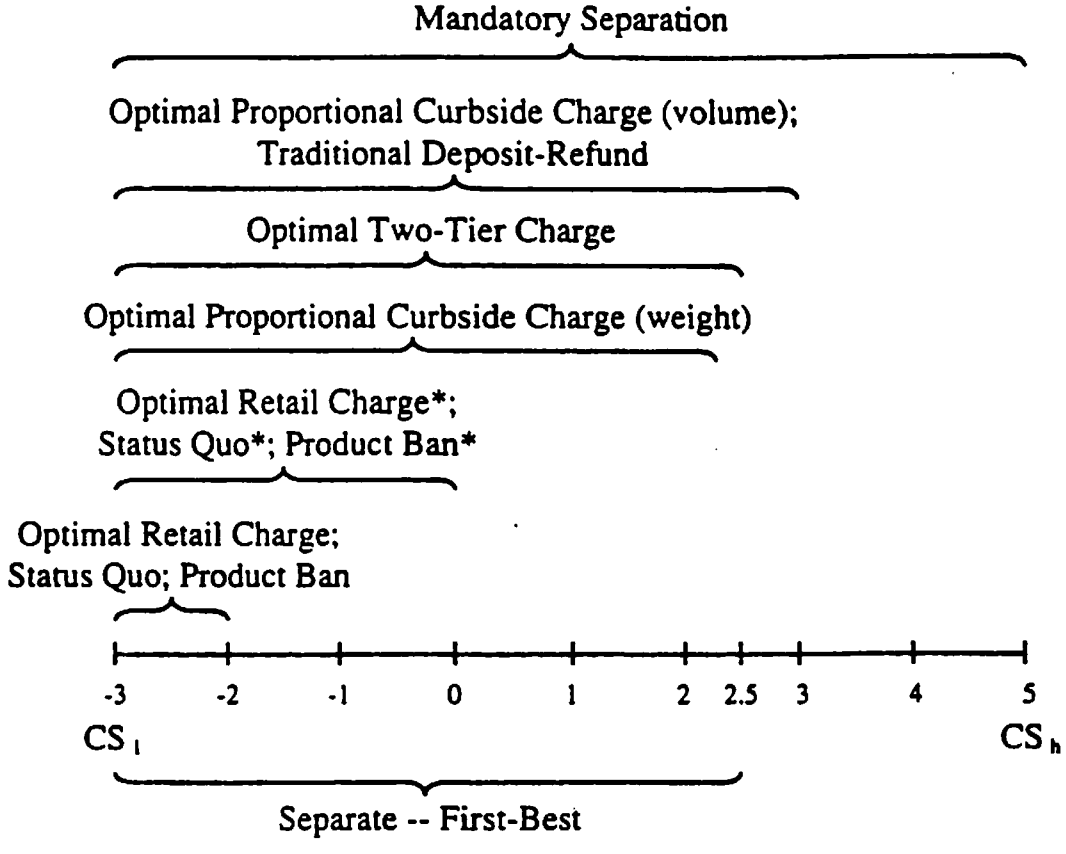
glass, consume significantly more landfill volume per container than glass. (Menell (1990) at 662 n.23).

Separated clear glass is currently being sold for between $50 and $80 per ton (Recycling Times (1989) at 3 (price at buyer's dock)), which is between 2.5¢ and 4¢ per 1 pound glass container. Taking into consideration the costs of collection, initial processing, and the costs of operating a recycling facility, we assume a net salvage value for separated glass (DC_2^s) of .5¢.

FIGURE 3

Disposal Incentives



*Assuming voluntary curbside collection of separated glass containers.

the first-best allocation of resources is traced out as follows. Given the large differential between the costs of disposing separated glass and non-separated plastic (3.5¢), all consumers with low costs of separation (i.e., between -3¢ and -1.5¢) should purchase glass. As costs of separation rise above -1.5¢, it becomes optimal for those consumers with the strongest preference for plastic packaging (i.e., low r^j) to purchase plastic. Therefore, the critical value for the subjective preference for packaging increases one-for-one with increases in the costs of separation. This occurs until a cost of separation of 2.5¢ is reached. At and above this level, it is optimal for consumers who purchase glass not to separate their glass containers. Consequently, the critical value of the subjective preference for packaging remains at -1¢, the difference in the disposal cost of plastic and non-separated glass, for costs of separation between 2.5¢ and 5¢ (CS_h). The shaded area in Figure 4 represents the percentage of consumers who should purchase plastic under the first-best allocation of resources.

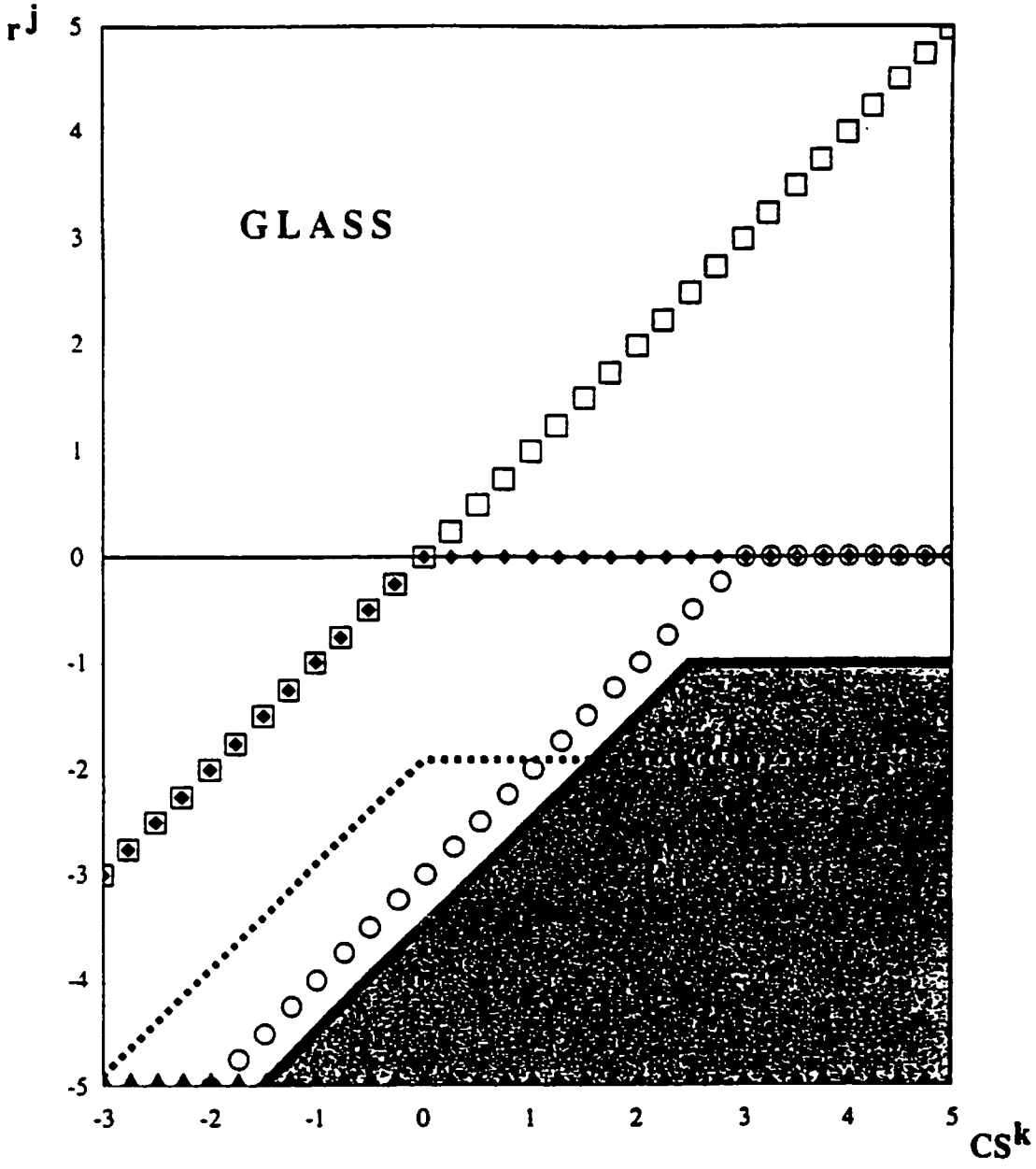
[FIGURE 4]

The purchasing incentives of the other policies can readily be assessed by comparison to this shaded area. The optimal proportional curbside charge policy (based on volume) and the optimal retail charge policy (with curbside pick-up of separated as well as unseparated refuse) come relatively close to the first-best purchasing incentives. The mandatory separation policy, by effectively imposing a charge of the cost of separation on glass purchasers, results in greatly excessive purchases of plastic containers across the range of costs of separation. By contrast, the packaging ban results in too few purchases of plastic. The traditional deposit-refund policy, by having no effect on relative product prices causes consumers to base their purchase decisions solely on their subjective preference for packaging.

Table 3 summarizes the social welfare effects of the solid waste regulatory policies. The first-best policies result in 21.1% of consumers purchasing plastic and 78.9% of consumers purchasing glass. Of the glass purchasers, 76.2% separate and 23.7% do not. The optimal proportional curbside charge policy achieves slightly too many plastic purchases and slightly too much separation by the glass purchasers. The optimal retail charge policy with curbside collection comes quite close to the optimal purchase decisions, but results in far too

FIGURE 4

Comparison of Purchasing Incentives*



Symbol	Policy
▬▬▬	First-Best
□□□□	Mandatory Separation
———	Traditional Deposit-Refund
◆◆◆◆◆	Status Quo
○○○○○	Optimal Proportional Curbside Charge
••••••••••	Optimal Retail Charge
▲▲▲▲▲	Product Ban

*Selected parameter values:

Parameter	Value
P_2-P_1	0¢
(r_l, r_h)	[-5¢,5¢]
(CS_l, CS_h)	[-3¢,5¢]
d_0	2¢
dr	5¢
DC_1^a	3¢
DC_2^a	2¢
DC_2^b	-.5¢
v_1, v_2	1 liter

little separation. The status quo, the traditional deposit-refund policy, and particularly the mandatory separation policy result in far too much purchasing of plastic; in the case of mandatory separation, almost three times the optimal amount. The product ban results in far too little purchasing of plastic. The mandatory separation policy results in too high a percentage of separation by glass purchasers. The status quo, optimal retail charge policy, and product ban policy result in far too little separation. The traditional deposit-refund policy, while coming close to the optimal percentage of glass separation, results in wasteful efforts to separate plastic and encourages many consumers who should purchase and separate glass to purchase plastic instead (Compare Porter (1978)).[18]

[TABLE 3]

The optimal multi-tier charge, for these parameter values, achieves the first-best allocation of resources. The optimal proportional curbside charge policy (based on volume) comes within 0.2% of the level of social welfare achieved under the first-best. The optimal retail charge policy with curbside collection achieves almost 98% of the first-best. Mandatory separation produces 95% of the first-best level, while the optimal retail charge without curbside collection produces 92.2%. The status quo achieves 91.6% of the first-best level. The product ban and the traditional deposit-refund policies perform the worst, generating 87.5% and 86.3% of the first-best level of social welfare, respectively.[19]

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[18] The analysis of this paper suggests a straightforward way of improving the efficacy of deposit-refund systems. Purchasing and disposal incentives could be improved by basing deposit-refund amounts on actual social disposal costs. This approach could cause deposit and refund amounts to differ for particular containers.

[19] It must be kept in mind that these results are based on the particular assumptions underlying the model and the parameter values. Among the effects not considered are the social benefits of reducing litter and the possibility that someone other than the consumer will recycle an empty container, both of which occur with the traditional deposit-refund policy.

TABLE 3

Comparison of Social Welfare Effects*

Regulatory Policy	Social Welfare (% of First-Best)	Purchasing		Glass Separation	
		percent plastic	percent glass	percent separated	percent not separated
First-Best Allocation	100	21.1	78.9	76.2	23.7
Optimal Two-Tier Charge	100	21.1	78.9	76.2	23.7
Optimal Curbside Charge**	99.8	27.5	72.5	82.8	17.2
Optimal Retail Charge***	97.8	25	75	42.2	57.8
Mandatory Separation	94.7	60	40	100	0
Status Quo	91.6	49.4	50.6	13.6	86.4
Product Ban	87.5	0	100	12.5	87.5
Traditional Deposit-Refund	86.3	50	50	75****	25****

* This simulation is based on the following parameter values:

Parameter	Value	Parameter	Value	Parameter	Value
P_2, P_1	80¢	DC^n_1	3¢	v_1	1 liter
(r_l, r_b)	[-5¢,5¢]	DC^n_2	2¢	v_2	1 liter
(CS_l, CS_b)	[-3¢,5¢]	DC^r_2	-.5¢	dr	5¢
U_o	95¢	d_o	2¢		

** Based on volume.

*** With voluntary curbside collection of separated glass containers.

**** Applies to both plastic and glass containers.

III. The Choice of an Optimal Policy in the Presence of Administrative Costs

The desirability of a particular policy depends on its costs of implementation as well as its efficacy in correcting distortions. This section first describes how administrative costs can be incorporated into the comparative framework. It then discusses the magnitude of these costs.

1. Incorporating Administrative Costs into the Analysis

Administrative costs can be introduced into the policy analysis in the following straightforward manner.[20] The cost of curbside pickup of mixed refuse is some constant per household (β_0). Collecting separated items imposes an additional cost per household (β_1). Weighing (or measuring the volume of) mixed refuse and assessing a charge imposes yet another cost per household (β_2).[21] The administrative costs associated with retail surcharges are assumed to have a similarly simple structure. There is a per item cost for assessing a charge (τ_1), and, in the case of the traditional deposit-refund policy, a processing cost per redeemed item (τ_2). The model assumes that a product ban would be costless to implement.

The optimal regulatory policy in the presence of administrative costs is the policy that yields the highest net social welfare. In general, where both curbside and retail administrative costs are low, the optimal multi-tier charge policy performs best because it provides optimal incentives for both disposal and purchasing decisions.[22] For low values of curbside administrative costs and

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[20] The structure of transaction costs can influence the design of the particular types of regulatory policies (Polinsky & Shavell (1982)). Such effects, however, are likely to be of secondary significance.

In addition to the direct costs of implementation discussed in the text, all of the incentive approaches described require policymakers to determine the social costs of disposal. There are significant economies of scale in making these valuations (Menell (1990)).

[21] Adoption of a curbside charge might also create problems such as illegal dumping or, where credits are available for separated refuse, theft. Such problems would raise the enforcement costs, which are a type of administrative cost, for such policies.

[22] Since the perfect curbside charge and perfect deposit-refund policies would be extremely expensive to implement, the analysis in this section focuses

high values of retail administrative costs, the optimal proportional curbside charge policy performs best.[23] Inversely, for low retail administrative costs combined with relatively high curbside administrative costs, the optimal retail charge policy is preferable to the others. Where both curbside and retail administrative costs are high, the status quo tends to be preferred.

As an illustration of these effects, Figure 5 shows how the optimal policy varies with changes in administrative costs for the parameter values used in the previous section. For a community in which the average household consists of four persons who consume one bottle of sparkling water per day, the optimal multi-tier charge policy is preferred when $\beta_2 < 10.6¢$[24] and $r_1 < .03¢$ per item. As the administrative cost of measuring refuse increases, the optimal retail charge policy (with voluntary curbside separation) becomes most cost-effective. The optimal proportional curbside charge policy becomes preferable as the costs of implementing the retail surcharge rises. When the administrative costs of the retail charge policy and the proportional curbside charge policy rise above .15¢ per item and 13.9¢ per household respectively, then the status quo (with voluntary curbside collection) becomes preferred because the implementation costs of any other policy outweigh the social and environmental benefits of tighter regulation.

[FIGURE 5]

This pattern helps explain why the United States has moved slowly in developing better solid waste policies, as well as why change is likely to occur at an increasing rate. Until recently, the perceived (although not actual) cost of landfill disposal was very low. Moreover, the costs of weighing unseparated refuse at the curbside or using systematic retail charges were high relative to these perceived costs. As the next sub-section discusses, technological advancements have substantially reduced the administrative costs of incentive-

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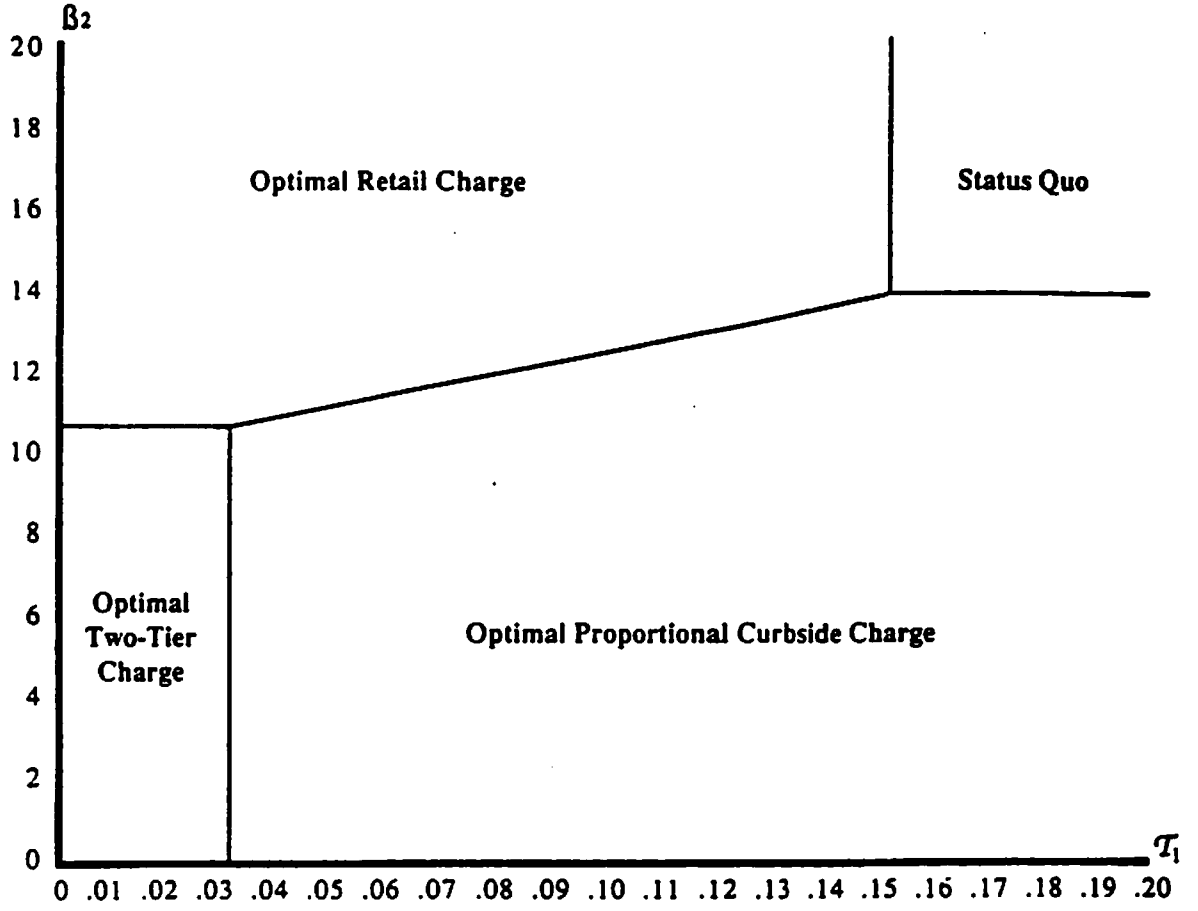
upon the other policies.

[23] If β_1 is low and β_2 is high, it is possible for mandatory separation to be preferable. As the next sub-section will discuss, however, there are good reasons for believing that β_2 is unlikely to be high.

[24] We assume that refuse is collected on a weekly basis and that $\beta_0 = 50¢$ per household $\beta_1 = .03¢$ per household.

FIGURE 5

Optimal Solid Waste Regulatory Policies for Selected Transaction Costs*



*$ß_0$= 50¢ per household; $ß_1$ =10¢ per household; τ_1= .5¢ per container returned

based policies.

2. The Magnitude of Administrative Costs: Technological Factors

The principal administrative costs of economic incentive systems relate to monitoring. Recent technological advances have substantially reduced these costs.

The administrative costs of implementing the optimal proportional curbside charge policy are similar to the costs of charging for electricity, natural gas, and water use. In the context of these traditional public utilities, the principal administrative costs are meter reading and billing. These costs have been substantially reduced with the development of data processing technologies.

With the optimal proportional curbside charge policy, trash collectors would have to measure the weight or volume of the unseparated refuse and load separated items into a few categorized bins (e.g., paper, glass, metal, plastic). With traditional garbage truck design, this separation would be quite costly. It is possible, however, to design vehicles with multiple bins for separated materials and scales (or other devices) for measuring the weight or volume of unseparated refuse.[25] On-board computers could calculate the refuse charge for each household as the refuse was collected. At the end of a daily run, this data could be "dumped" into a main computer which would prepare individualized customer bills. As these technologies continue to develop, it will be possible to move toward a perfect deposit-refund scheme in which households would be credited for the value of separated items based on actual resource recovery values.

As the innovative waste disposal programs in Perkasie, Pennsylvania and Seattle, Washington attest, the administrative costs of curbside charges might be reduced in even simpler ways. Perkasie's plan of requiring households to purchase specially designated trash bags and Seattle's system of charging on a monthly basis for the use of receptacles of particular sizes creatively minimize

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[25] For landfilled refuse, the appropriate measure is compacted volume. Since the compactness of household refuse can vary significantly, especially if some households use trash compactors, weight may be the best feasible measure.

administrative costs.[26] The technologically sophisticated system described above would provide more flexibility and convenience than these approaches, but would likely result in higher implementation costs.

At first blush, the cost of implementing a system that accurately adjusts relative retail prices to reflect social disposal costs would appear to be prohibitively expensive. The typical grocery store sells 10,000 to 15,000 products. If clerks had to individually mark the added charge for each item, the administrative costs would indeed be exorbitant. This would be especially true if social disposal costs change over time, as they probably would with the development of new disposal technologies or changes in consumer separation behavior.

Recent advances in scanning technology, coupled with the widespread adoption of the Universal Product Code (UPC) (also known as bar codes), however, suggest the possibility of implementing a surprisingly low cost yet highly flexible system of adjusting relative retail prices to reflect social disposal costs. Many retail outlets currently use optical scanners, which read UPCs to identify the product being purchased. A computerized cash register looks up the price assigned to each product, as well as any applicable taxes, and rings the amount up on the consumer's bill. If data on the amount of disposable materials in each product, recycling rates for different materials, and the true social disposal costs of different materials were input into the computer, this system could be used to assign individualized disposal charges to retail products. Optical scanning technology is already used for more than 60% of retail grocery sales in the United States and its use is growing at a rapid rate. Therefore, the administrative costs of the optimal retail charge policy might not be prohibitive.

3. The Magnitude of Administrative Costs: Community Factors

The administrative costs of solid waste policies depend significantly upon

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[26] The Perkasie "per bag" approach is more effective than the Seattle "per can" charge because consumers are not registered for a specific size receptacle per week. Whereas Seattle households reap no financial benefit from disposing less than the capacity of their registered receptacle, Perkasie households can save money by putting out fewer bags over time.

the population characteristics of the community. Curbside charges are likely to work best in communities where refuse is collected one household at a time, such as lower density urban neighborhoods, suburban areas, and rural communities. These communities are ideally suited to the optimal multi-tier charge and optimal proportional curbside charge policies.

On the other hand, curbside charges will be most difficult to implement when many households use common trash receptacles, as in most apartment dwellings. Unless extensive monitoring is employed or new disposal systems are designed, apartment residents will be able to dispose of refuse as they wish. Perhaps the best way of directly regulating their disposal decisions would be through a combination of education programs, the provision of convenient bins for separated materials, and the fostering of a community spirit of conservation. In neighborhoods where most people reside in large apartment complexes, retail charges combined with conveniently located recycling drop-off centers offering the salvage value for separated refuse are likely to be the best economic incentive system for regulating the solid waste stream.

Most communities will have some small grocery stores that do not use scanners, due to a lack of either knowledge or resources. It might not be cost-effective to require these establishments to adopt the retail charge system. In order to prevent these stores from obtaining a competitive advantage from the adoption of an optimal retail charge system, the community could introduce a compensating uniform excise tax for these establishments. Although there would still be differential effects on particular products, the average effect on grocery bills would be similar to that of retail disposal charges. Moreover, since small stores typically charge higher prices in any case, it is unlikely that many consumers will selectively purchase from these locations. As scanning technology becomes more widely adopted, both because of government policies encouraging its use and cost-reducing technological innovations, this problem will diminish.

The disposal methods used by the community will also be important to the design of the optimal incentive system. Since the transaction costs of curbside collection of separated items, as well as residents' separation costs and participation rates, rise with the number of items collected at the curbside, only those items whose collection will be economically advantageous should be

separated. Selections should be made on the basis of the net value of separated materials, and the costs or benefits of disposing of the materials through the community's normal disposal route. For example, a community which relies upon incineration would benefit from using curbside separation to remove glass, metal, and compostable wastes from the unseparated waste stream, but might not wish to remove plastics. In addition, communities will want to carefully consider the compatibility of disposal technologies. For example, composting programs and incineration are quite complementary because food and yard wastes have a low heat content.

IV. Generality and Limitations of the Analysis

Any model of a process as complex as the American household's purchasing and disposal decisions cannot capture all of the relevant factors and interactions. Some limitations of the model understate the strength of the main results; others overstate them.

The analysis assumes that only one product and two packaging types exist. The solid waste stream, however, reflects tremendous diversity of product and packaging types. Modelling consumer decisions for all products simultaneously would be extremely difficult. While such a modelling effort might be useful, the basic assumptions of the simpler model used here capture the essential aspects of consumer decisionmaking. To a large extent, consumers, even in a multi-product world, first determine what products they would like to purchase. After this decision is made, they select a packaging type. While the availability of packaging types may sometimes influence product selection, in general it seems reasonable to model the packaging choice as independent from the product choice. Moreover, as noted below, the fact that there are many products actually strengthens the case for using flexible policy instruments that directly adjust relative retail and curbside prices.

Nonetheless, municipalities will not be able to set an optimal curbside charge based only on disposal costs for two packaging types. If a single curbside charge is used it will have to be an average for many waste types, including other packaging, food waste, and yard debris, among others. The need to produce a single averaged curbside charge means that the charge selected will

overstate the disposal costs of some materials while understating the disposal costs of others.[27] Therefore, it is important to analyze the sensitivity of total social welfare under the optimal multi-tier and proportional curbside charge policies to deviations from the optimal value for the proportional curbside charge. Because the multi-tier charge policy has a flexible retail charge component, the social welfare produced by this policy is less sensitive to deviation from the optimal curbside charge. As a rough measure of this sensitivity,[28] if the charge is set at one-third its optimal value, social welfare drops slightly less than 1% from the first-best level. When the charge is raised 50% above its optimal value, social welfare declines less than 0.5% from the first-best.

Because the curbside charge policy does not have the counterbalance of adjustable retail charges, it is somewhat more sensitive to variations from the optimal curbside charge. When the charge is one-third of its optimal level, social welfare is still within 2% of the first-best. When the curbside charge is 50% above its optimal value, social welfare under this policy is about 1.2% less than the first-best.

In many ways, the support for economic incentive approaches is stronger than suggested by the particular model used. As framed, the model focuses solely on the choice between two containers of the same size. Economic incentive approaches also encourage better decision-making with respect to many other factors, including container size, product durability, and product choice. Larger capacity containers will in general reflect a lower disposal cost per measure of volume because the volume of a container increases with the cube of the radius, while the surface area, which determines the amount of disposable material, increases with the square. Therefore, economic incentive systems create an incentive for consumers to purchase higher capacity containers. Similar logic applies to product durability. Products with longer lives need not

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[27] If disposal costs are perfectly correlated with compacted volume for all materials and weight is perfectly correlated with compacted volume, then curbside charges can perfectly reflect social disposal cost. Otherwise, there will be distortions.

[28] The sensitivity to distortions in α depend on the absolute magnitude of the optimal α. The analysis in the text is based on the parameter values used in the simulation discussed earlier.

be disposed as frequently. Therefore, to the extent that consumers can factor these effects into their decisions, products featuring greater durability will be preferred, all other things the same. Similarly, where substitute products exist, economic incentive systems will discourage the use of products that produce more expensive solid waste. Thus, consumers will be more inclined to purchase reusable containers and products with less packaging. These incentive effects will feed into manufacturer incentives to develop and offer containers of lower disposal costs per volume and products of longer life.

These factors underscore the intuition underlying the advantages of economic incentive approaches over less flexible regulatory policies.[29] Economic incentive systems adjust relative prices to reflect social costs, thereby enabling heterogeneous consumers to decide on the basis of their own preferences and costs what products to purchase and how to dispose of them. By contrast, mandatory separation and product ban policies specify uniform modes of behavior for all people. Given the diversity of consumers, these policies are prone to over and under-inclusiveness. The traditional deposit-refund system avoids the stringency of the mandatory separation and product ban policies, but also fails to provide correct incentives by not basing deposit charges and refunds on true social costs. Moreover, in many cases, the traditional deposit-refund system relies upon an inefficient collection method.

The treatment of administrative costs also excludes some relevant factors. There may be economies of scale in collection of separated materials. For this reason, it may be important to achieve a target participation rate for curbside separation. While this provides some justification for a mandatory separation policy, it also favors the optimal multi-tier charge or proportional curbside charge policies. Although the mandatory separation policy did achieve a higher separation rate in our example (100% versus 76.2% and 82.8% respectively), the optimal policies actually resulted in more glass containers being separated

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[29] The general conclusions of the analysis are consistent with policy analyses of other environmental problems. Policies that price environmental costs better have long been recommended to address air and water pollution (Stewart & Krier (1978) at 555 - 615) A major problem in pursuing these policies, however, has been the lack of established markets for air and water resources. Since markets already exist for pricing consumer products and municipal services, the proposed optimal charge policies can be adopted, designed, and implemented relatively easily.

because so many more households purchased glass.

Furthermore, certain disposal options may not be available if particular types of materials are in the waste stream. For example, incineration may not be possible if certain toxic materials are found in the waste stream. The attractiveness of incineration for a particular community, therefore, might justify a deposit-refund system or a product ban. On the other hand, the optimal multi-tier charge and optimal retail charge policies could also effectively reduce the amount of toxic materials in the waste stream through appropriate charges.

A further limitation of the model is its treatment of consumer preferences (costs of separation and packaging preferences) as uniformly distributed and essentially fixed over time. Propositions 1, 3, 6, and 7 - 12 hold for any continuous distributions of CS and r. The latter assumption — static preferences — is more problematic, especially given the responsiveness of households to pilot education and separation programs (Menell (1990) at 713). The mandatory separation policy might quickly educate people about the ease of separation. As above, however, it is likely that curbside and retail charges would have a similar effect, although perhaps not as pronounced.

A related restriction of the model is the assumed independence of the cost of separation (CS) and the relative preference for packaging types (r). It is possible that people who are environmentally sensitive have low costs of separation (because they get satisfaction from reducing the waste stream) and prefer packaging types that are easily and completely recyclable. This correlation, however, would merely mean that there is a distinct sub-group within the population that does the "right thing." The model therefore, would merely apply to the non-environmentally conscious, the people who policymakers seek most to influence.

The promise of economic approaches to solid waste regulation need not be judged solely on the basis of the theoretical predictions of the model. Although experimentation with novel approaches to solid waste regulation is relatively recent, the Perkasie, Pennsylvania example, involving a suburban community of 6,500 people, provides strong support for the general conclusions of the

analysis.[30] From 1987 (the year before the program was implemented) to 1988, the total amount of unseparated solid waste collected in Perkasie fell from 2,573 tons to 1,038 tons, representing a 59% reduction. This resulted in a saving of more than $90,000 in direct disposal costs (using Perkasie's 1988 tipping fee of $59 per ton). In addition, the town earned $15,456 from the sale of aluminum and paper. On the cost side, the 1988 worker-hours for loading separated and unseparated wastes (2,781 hours) increased by only 18% over the average for 1985 to 1987 (2,273 hours). The full capital cost of the program (including a recycling trailer, modifications to the refuse vehicle, and recycling buckets) was less than $25,000. The cost of separation borne by residents aside,[31] the program is a success both financially[32] and in terms of reducing solid waste.

V. Conclusions

By assuming an extremely simple structure to environmental externalities and government regulatory institutions, the traditional optimal taxation framework obscures many of the difficult design questions facing regulators. Building upon a richer description of the externalities reflected in the municipal solid waste stream, this paper has developed a multi-tier framework for characterizing and analyzing policy instruments.

The analysis concludes that while comprehensive monitoring systems would be prohibitively expensive, there are feasible economic incentive systems that would be extremely effective in reducing the quantity and improving the composition of the municipal solid waste stream. Proportional curbside charges, based on the volume or weight of mixed refuse, provide strong incentives for

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[30] The information for this case study is provided in Institute for Local Self-Reliance (1989) at 47 - 55.

[31] There is no data measuring this cost. Since the borough requires separation, the cost of separation borne by residents might be significant.
The revenue raised through the sale of garbage bags are not social costs (except for the resource cost of the bags) because these funds are used to pay for the waste disposal and resource recovery operation. Prior to 1988, Perkasie simply charged each household an annual fee of $120 for refuse removal.

[32] Overall, the town paid 40% less for garbage disposal than a year earlier (Paul (1989)).

source reduction, separation of valuable materials, and purchasing of materials that are resuable, recycable, and less expensive to dispose. Another attractive option is a highly flexible system of retail charges implemented by entering data on disposal costs into optical scanning cash register systems. This system would facilitate carefully tailored adjustments to individual product prices to reflect disposal costs. If this pricing system were combined with a curbside charge, even greater social benefits could be reaped.

By contrast, the approaches that the federal, state, and local governments have preferred thus far to address solid waste problems create perverse and counterproductive incentives. Although mandatory separation requirements, bans on plastic packaging, and traditional deposit-refund policies being implemented or seriously considered by many state and local governments have some beneficial effects, they fail to provide appropriate incentives for solid waste reduction and disposal. In some plausible circumstances, the distortionary effects of these policies outweigh their benefits.

At a more general methodological level, economists need to focus more attention on the development of richer, multi-tier frameworks for the analysis of environmental externalities. Few modern environmental problems are of the "end of the pipe" variety. Even fewer can be remedied most efficaciously through a single "optimal" tax.

Consider the case of automobile pollution, which is often characterized as a relatively simple "end of the pipe"/optimal tax regulatory problem. The external costs of an automobile depend upon its design characteristics, when and where it is driven, how much it is driven, and the driving habits of the operator. The air pollution of the automobile can be regulated through gasoline taxes, fuel standards, on-board equipment requirements (e.g., catalytic convertors), inspection requirements, odometer charges, toll charges, automobile taxes, fuel efficiency charges, and fuel efficiency standards, among others. A complete appreciation of this problem will not be realized until the complex nature of the externality and the cost structure of regulation are analyzed in a comparative multi-tier framework.

References

Dales, J.H., Pollution, Property and Prices (1968).

Franklin Associates, Ltd., Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988) (Mar. 30, 1988) (prepared for EPA).

Glenn & Riggle, Biocycle Survey: Where Does the Waste Go? Biocycle 34 (Apr. 1989).

Institute for Local Self-Reliance, Beyond 25 Percent: Materials Recovery Comes of Age (1989).

Laffont, J., Fundamentals of Public Economics (1988).

Menell, Beyond the The Throwaway Society: An Incentive Approach to Regulating Municipal Solid Waste, 17 Ecol. L. Q. 655 (1990).

Office of Technology Assessment, U.S. Congress, Facing America's Trash: What Next for Municipal Solid Waste? (1989).

Organization for Economic Cooperation and Development, Economic Instruments in Solid Waste Managmenet (1981).

Paul, Pollution Solution: Pennsylvania Town Finds Way to Get Locals to Recycle Trash, Wall St. J. 1 (Jun. 2, 1989).

Polinsky and Shavell, Pigouvian Taxation with Administrative Costs, 19 J. Pub. Econ. 385 (1982).

Porter, A Social Benefit-Cost Analysis of Mandatory Deposits on Beverage Containers, 5 J. Envtl Econ. & Mgmt. 351 (1978).

Recylcling Times, The Markets Page (May 23, 1989).

Sandmo, Optimal Taxation in the Presence of Externalities, 77 Swed. J. of Econ. 86 (1975).

Stewart, R. & Krier, J., Environmental Law & Policy (2d ed. 1978).

U.S. Environmental Protection Agency, Office of Solid Waste, Waste Dilemma: An Agenda for Action, Background Document (1988).

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