JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT **29**, 78–91 (1995)

Garbage, Recycling, and Illicit Burning or Dumping

DON FULLERTON

Department of Economics, University of Texas at Austin, Austin, Texas 78712

AND

THOMAS C. KINNAMAN

Department of Economics, Bucknell University, Lewisburg, Pennsylvania 17837

Received July 15, 1993; revised February 18, 1994

With garbage and recycling as the only two disposal options, we confirm prior results that the optimal curbside fee for garbage collection equals the direct resource cost plus external environmental cost. When illicit burning or dumping is a third disposal option that cannot be taxed directly, the optimal curbside tax on garbage changes sign. The optimal fee structure is a deposit–refund system: a tax on all output plus a rebate on proper disposal through either recycling or garbage collection. The output tax helps achieve the first-best allocation even though it affects the choice between consumption and untaxed leisure.

1. INTRODUCTION

Solid waste disposal has become more expensive recently due to rising land prices, strict environmental regulations, and host fees paid to localities to accept new landfills or incinerators. Tipping fees in the northeastern U.S. approach $125 per ton. Most towns still pay for garbage collection and disposal using general revenues, however, with no price per bag. Thus the resident views it as free.

As an alternative, more towns are beginning to sell special bags or stickers necessary for curbside collection of each bag or can of garbage (U.S. EPA [20]). These per-unit charges can help defray the cost of collection, and they help discourage waste. Two major recent studies describe the advantages of such charges. Project 88—Round II [14], sponsored by then Senators Timothy Wirth of Colorado and John Heinz of Pennsylvania, says that unit pricing "creates strong incentives for households to reduce the quantities of waste they generate, whether through changes in their purchasing patterns, reuse of products and containers, or composting of yard wastes" (pp. 49–50). The World Resources Institute (WRI, Repetto *et al*, [15]) further extols the virtues of "pay-by-the-bag." For densely populated areas, they estimate that each 32-gallon bag of garbage costs $1.12 in direct payments to waste haulers and landfill operators, and $1.83 including external costs to others near the landfill who may suffer from noise, odor, litter, and extra traffic. They go on to measure welfare gains from charging such a price.

In response to unit charges, however, households might not just recycle, compost, and adjust purchasing habits. They might also burn paper in fireplaces and carry trash to commercial dumpsters, back woods, and vacant lots. If New York City were to sell stickers for $1.83 each, and pick up only bags with stickers, we believe that revenue would be small and piles of unidentified garbage would be large. Welfare gains would be negative.

0095-0696/95 $12.00

Should garbage be taxed to reflect its negative externality, or subsidized to avert illicit dumping? Maybe recycling should be subsidized. If not, could the same effect be achieved by a tax on virgin materials? What is the role for deposits on purchases with refunds on returns.

To address these questions, we build a simple theoretical general equilibrium model of household choice between consumption and leisure, and among three disposal options: garbage, recycling, and illicit burning or dumping. A single consumption good is produced using a single primary factor, recycled input, and virgin materials such as timber or minerals. We later consider disaggregate goods and services. The model also includes three externalities. First, municipal garbage collection and disposal may impose aesthetic and health costs on those who live near the landfill or incinerator. Second, improper burning and dumping may impose even higher costs on others. Third, the extraction of virgin materials involves clear-cutting or strip-mining that may adversely affect not only the landowner who sells timber or mineral rights, but others who enjoy wilderness and wildlife.

Others have addressed some of the above questions, usually with partial equilibrium models and only two disposal options. First, Sullivan [18] compares legal and illegal disposal. He finds both an optimal subsidy on legal disposal and an optimal degree of enforcement against illegal disposal. These are second-best policies since he does not allow for a tax on consumption (or, equivalently, a "deposit" upon purchase). Also, Dobbs [5] and Project 88—Round II [14] have discussed the problem of litter as a reason for deposits and refunds on particular commodities. Copeland [3] builds a general equilibrium model with international trade and waste from production, but no recycling or waste from consumption. Jenkins [6] and Sigman [16] consider waste and recycling, but not illegal dumping. Several other models of household decisionmaking deal with various important aspects of the solid waste problem, but also ignore illicit dumping (e.g., [4, 10, 15, 21]). Our study is unique in that (1) we address all of the above questions in (2) a single general equilibrium framework with (3) enough instruments to solve for first-best policies, and when (4) households can choose among all three disposal options: garbage, recycling, and illicit burning or dumping. Another advantage, we believe, is that our solution can be replicated easily on the back of an envelope.

To introduce our notation, and to characterize prior results, we start in Section 2 with a simple model in which garbage and recycling are the only two disposal choices. In this case the WRI study [15] is correct that the optimal garbage collection fee includes not only the direct resource cost ($1.12 per bag) but also the external cost (for a total of $1.83 per bag, in their study).

In Section 3, we add illicit dumping as a third disposal option. When all tax instruments are available, the first-best solution can be achieved by waste-end taxes on garbage *and* on illicit dumping. Not surprisingly, these two tax rates reflect only the corresponding externalities. Suppose, however, that a tax on illicit dumping is difficult or impossible to enforce. Does this mean that the first-best can no longer be supported? No. In general equilibrium, only relative prices matter—and therefore any tax can be set equal to zero as long as taxes on all other relevant activities are adjusted so as to induce first-best relative prices. Several points follow directly from this general equilibrium insight.

First, with the tax on illegal dumping set equal to zero, the proper relative price between legal and illegal disposal can be induced by subsidizing legal disposal (both garbage and recycling). That is, the optimal tax on garbage switches to a subsidy. If this subsidy for garbage is close to the direct resource cost ($1.12), then free collection of garbage is quite sensible.

Second, this subsidy for legal garbage disposal tends to subsidize consumption since it lowers the cost of waste disposal. Therefore, to restore the proper relative prices in general equilibrium, a tax on consumption is required. This result addresses a debate in the literature about whether optimal fees would be imposed "upstream" at the point of production, or "downstream" at the point of disposal.[1] In our model, if the downstream tax on illicit dumping cannot be enforced, the same first-best can be achieved by using an upstream tax instead. Consumption should be taxed at a rate that reflects not the good's disposal cost, but its possible externality from illicit burning or dumping. This tax is then returned as a subsidy on recycling and on proper disposal of garbage, leaving an implicit tax on burning or dumping. The result is a deposit–refund system, as in Bohm [2], but it applies to all consumption goods rather than just bottles or lead–acid batteries.

Third, many have suggested that recycling be encouraged by a tax on virgin materials (e.g., [9, 14, 16, and 19]). No such role arises in our model. Virgin materials are only taxed if their extraction has a negative externality (e.g., strip mining). Section 4 shows that if recycling *cannot* be subsidized for some reason, then all of the proper relative prices can still be achieved with a tax on virgin materials and on *all* other inputs except recycling.

Fourth, existing public finance literature generally finds that a consumption tax distorts the choice between taxed consumption and untaxed leisure. Here, we find that a consumption tax is part of a first-best policy, even though leisure is still untaxed. The reason is simply that consumption leads to disposal problems while leisure does not.

Section 5 considers disaggregate consumption goods, and Section 6 briefly discusses population density, multiple levels of government, and administrative cost.

2. JUST GARBAGE AND RECYCLING

Most models of household solid waste behavior ignore the possibility of illicit burning or dumping (e.g., [4, 6, 10, 15, 16, 21]). We therefore start with garbage and recycling as the only two disposal choices. The purpose of this section is not to provide any new results, but to set up our notation and to characterize prior results. Since none of the the discussion above involves distributional issues, we consider a single jurisdiction with n identical individuals or households. Each buys a single composite consumption good c, and each generates waste in two forms. We use g for garbage collection, and r for recycling and subsequent reuse in production. These alternatives are substitutes in the "technology" of household

---

[1] Wertz [21] finds that a (downstream) per-unit garbage fee raises the effective purchase price of goods with high disposal content. Menell [8] suggests retail disposal-content charges that reflect the subsequent disposal cost of each item. Porter [13] analyzes a deposit–refund system for bottles. Sigman [16] finds that a tax on virgin lead is equivalent to a deposit–refund system, when virgin lead and recycled lead are perfect substitutes in production. The pros and cons of alternative policies are nicely described in some of these papers, as well as in Miedema [9] and Project 88—Round II [14].

consumption,[2]

$$c = c(g, r), \tag{1}$$

where $c(\cdot, \cdot)$ is continuous and quasi-concave, and has positive first derivatives c_g and c_r. This relationship captures the degree to which the household is able to shift between disposal methods. With a given amount of consumption, the household may be able to reduce g and increase r by recycling newspapers, composting food waste, purchasing bottles in glass instead of plastic, collecting aluminum, and buying goods with less packaging. For simplicity, we specify each form of disposal as a single continuous variable. As a special case of (1), we will later discuss a "mass balance" example where $c = g + r$ (and $c_g = c_r = 1$).

Utility depends not only on household consumption, c, but also on home production, h, and the total amount of garbage, $G = ng$,

$$u = u[c(g, r), h, G], \tag{2}$$

where the first derivatives are $u_c > 0$, $u_h > 0$, and $u_G \leq 0$. For practical purposes, think of h as leisure use of time and resources. We use lower case letters to denote values per household and upper case letters for aggregates. Total garbage G may impose aesthetic and health costs, even if it is regulated in a "sanitary" landfill.[3]

On the production side of the model, output c may be produced using the constant returns to scale production function

$$c = f(k_c, r), \tag{3}$$

with input of resources k_c and recycled materials r from used consumption goods. Any reprocessing of r is folded into the production function. Also, just as we ignore transaction costs in the sale of c or k_c, we ignore the cost of collecting and trading r.

Provision of garbage collection services requires only one input, k_g, so constant returns to scale implies that production is linear. Home production uses resources k_h,

$$g = \gamma k_g, \quad h = k_h. \tag{4}$$

Finally, the model is closed by the resource constraint

$$k = k_c + k_g + k_h, \tag{5}$$

where k denotes a fixed total resource such as labor or capital. The results below do not require any distinction between labor and capital.

In this model, the social planner's problem is to maximize the utility of the representative household subject to the resource constraint, production constraints,

---

[2] Some readers may prefer to think of g and r as outputs of a function with input c, but Eq. (1) simply inverts that function. We think of g and r as amounts necessary to support c.

[3] In this static model of annual flows, G is total garbage per year. See V. L. Smith [17] for a dynamic treatment of waste flows into a landfill with a stock externality.

and $c(g, r) = f(k_c, r)$. The resource and production constraints can be substituted directly, to maximize

$$\mathscr{L} = u\left[c(\gamma k_g, r), k_h, n\gamma k_g\right] + \delta\left[f(k - k_g - k_h, r) - c(\gamma k_g, r)\right] \qquad (6)$$

with respect to k_g, r, and k_h. This optimization recognizes that every individual imposes costs on others through the use of garbage collection services.[4] The first-order conditions are

$$u_c c_g + u_G n = \delta(c_g + f_{kc}/\gamma) \qquad (7a)$$

$$u_c c_r = \delta(c_r - f_r) \qquad (7b)$$

$$u_h = \delta f_{kc}, \qquad (7c)$$

where f_{kc} is $\partial f/\partial k_c$, the marginal product of k used in the production of c. These equations will be employed shortly. They just indicate that the marginal utility made possible through additional g, r, or h must equal the marginal social cost.

For the case of private markets, individuals maximize utility in Eq. (2) subject to a budget constraint that may be affected by a tax or subsidy on each good,[5]

$$p_k k = (1 + t_c)c + (p_g + t_g)g + (p_r + t_r)r + p_k k_h, \qquad (8)$$

where p_k is the price earned on resources, the price of consumption equals one since c is numeraire, t_c is the tax per unit of consumption, p_g is the price paid for garbage collection, t_g is the tax per unit of garbage, p_r is the price paid by the consumer for recycling (which may be positive or negative), and t_r is the tax per unit of recycling. Note that consumers pays prices gross of tax, but producers receive prices net of tax. Here, however, households ignore the effect of their own activities on the total externality. Tax and subsidy rates can simply be set to zero for the case of private markets with no government interference.

Producers receive a price (= 1) for selling c, and they receive the price paid by consumers for recycling, p_r, which we said could be positive or negative. They maximize profits $(c + p_r r - p_k k_c)$ under perfect competition with constant returns to scale. Thus $f_{kc} = p_k$ and $f_r = -p_r$. Producers of garbage collection services similarly maximize $(p_g g - p_k k_g)$, so $p_g = p_k/\gamma$.

In this decentralized economy, the consumer chooses g, r, and h to maximize utility in (2) subject to the budget in (8). The resulting first-order conditions involve prices (p_k, p_r, and p_g), but we replace those with marginal products (f_{kc}, $-f_r$, f_{kc}/γ) to obtain

$$u_c c_g = \lambda\left[(1 + t_c)c_g + f_{kc}/\gamma + t_g\right] \qquad (9a)$$

$$u_c c_r = \lambda\left[(1 + t_c)c_r - f_r + t_r\right] \qquad (9b)$$

$$u_h = \lambda f_{kc}, \qquad (9c)$$

---

[4] We assume second-order conditions hold, solutions are internal, and a unique solution exists (see Baumol and Oates [1, pp. 37–38]).

[5] We ignore the government revenue requirement, assuming implicitly that lump-sum taxes are available to finance spending and to pay for necessary subsidies.

where λ is the marginal utility of income. These first-order conditions indicate that private marginal utility matches the cost to individuals of each activity. With tax rates of zero, it is easy to see that the outcome is not optimal. The right-hand sides of (7a) and (9a) would be similar, but only the left side of (7a) would account for the external cost of garbage, u_G.

With Pigouvian tax rates, however, private behavior in (9) can be induced to match the unique social optimum in (7). In this case, (7c) and (9c) indicate that $\delta = \lambda$. Since both problems maximize utility subject to a resource constraint, and both attain the same optimum, the social marginal utility equals the private marginal utility of the resource.

Next compare (7b) and (9b). By inspection, and using $\delta = \lambda$, these two equations will both hold when $t_c = t_r = 0$. In this model, no tax or subsidy is required for private behavior to yield this first-order condition of the social optimum.[6]

Finally, we compare (7a) and (9a). When $t_c = 0$, these equations both hold so long as $t_g = -nu_G/\lambda$. Since $u_G \leq 0$, this Pigouvian tax is ≥ 0. It increases with the size of the externality (u_G) and with the number of people adversely affected (n). To convert the tax into dollars, the marginal effect on utility, u_G, is divided by the marginal utility of income, λ.

Additional garbage collection is not a pure public good but uses scarce resources such as labor, capital, and landfill. Consumers should pay $(p_g + t_g)$, equal to \$1.83 per bag in the WRI study [15], enough to cover both the resource cost and the negative externality from garbage.

3. VIRGIN MATERIALS AND ILLICIT BURNING OR DUMPING

This section makes two modifications to the model. First, for each individual, we allow a third disposal alternative,

$$c = c(g, r, b), \tag{1'}$$

where b stands for burning and other improper disposal, such as dumping by the side of the road. Again b is a single continuous variable, and $c_b > 0$. With given consumption, the household may reduce g and raise b by burning cardboard boxes in the fireplace, carrying trash to commercial dumpsters, or leaving it out in the woods. Total $B = nb$ may reduce the utility of others. In the "mass balance" example, $c = g + r + b$.

Second, we consider virgin materials, with per capita use v. Aggregate use $V = nv$ also may reduce the utility of others. Implicitly, this cost may represent the shadow price of over-using scarce minerals in a more complicated dynamic model.[7] More explicitly, in our model, total V may reduce the public enjoyment of natural areas through clear-cutting or strip-mining. Cutting timber may reduce biodiversity

---

[6] Actually, this condition allows for any tax on consumption t_c, as long as it is returned as a subsidy for both garbage and recycling such that the net tax is still zero. We use this property below.

[7] Neher [11, Chap. 13] shows conditions under which (1) economies systematically underprice environmental resources (p. 238), and (2) the static optimizing solution is the steady state solution of a corresponding dynamic problem (p. 243).

and increase global warming. The new utility function is

$$u = u[c(g,r,b),h,G,B,V], \tag{2'}$$

where $u_G \leq 0$, $u_B \leq 0$, and $u_V \leq 0$. In addition, we assume that $u_B \leq u_G$. In other words, garbage is bad enough in the landfill but even worse if thrown by the side of the road.[8]

Production of c is modified to use not only labor and capital resources, k, and recycling input, r, but also virgin materials, v,

$$c = f(k_c, r, v). \tag{3'}$$

These virgin materials are produced or extracted using a simple linear function,

$$v = \alpha k_v. \tag{4'}$$

Each of these goods can be provided for a market price, but improper burning and dumping cannot. Yet illegal burning does involve time, psychic costs, and perhaps risk of getting caught. We assume that burning uses private resources $k_b = \beta(b)$, with marginal costs that are positive ($\beta_b > 0$) and rising ($\beta_{bb} > 0$). We also assume that any direct tax or penalty on burning or dumping would be difficult or impossible to enforce.[9] Finally, the resource constraint becomes

$$k = k_c + k_g + k_h + k_v + k_b. \tag{5'}$$

The social planner maximizes consumer utility (2′) in a Lagrangean like (6), subject to additional constraints (3′) through (5′), with respect to k_g, r, k_h, b, and k_v.[10] First-order conditions (7a, b, c) are unchanged, and

$$u_c c_b + u_B n = \delta(c_b + f_{kc}\beta_b) \tag{7d}$$

$$u_V n = \delta(f_{kc}/\alpha - f_v). \tag{7e}$$

For the case of private markets, competitive firms set the marginal product f_v equal to their cost in terms of market price plus tax ($p_v + t_v$). Other firms produce v and maximize profits $[p_v(\alpha k_v) - p_k k_v]$, so $p_v = p_k/\alpha$.

---

[8] We are grateful to a referee for pointing out that it is not sufficient to assume the u_B schedule lies below the u_G schedule. Both schedules may be decreasing (with B or G). We assume that the marginal unit of B entails more externality than the marginal unit of G, even though the amount of burning B may be much less than the amount of regular garbage G.

[9] See Lee [7] for a full treatment of enforcement costs and taxpayer avoidance costs. A simple enforcement model might suggest arbitrarily high penalties, in order to save real police resources. Our model avoids this problem in two ways. First, an internal solution for the social optimum implies that a certain amount of burning may be less costly in social terms than more landfill or recycling. The optimal tax on b is finite. Second, in our model, no direct tax on b is required or even desirable. As long as the government can enforce taxes or pay subsidies on market transactions (of c, g, r, and v), we show that the first-best allocation is attainable.

[10] The Lagrangean is

$$\begin{aligned}\mathscr{L} = {} & u\left[c(\gamma k_g, r, b), k_h, n\gamma k_g, nb, n\alpha k_v\right] \\ & + \delta\left[f(k - k_g - k_h - k_v - \beta(b), r, \alpha k_v) - c(\gamma k_g, r, b)\right].\end{aligned}$$

The consumer's budget constraint in (8) must now include the cost of burning, $p_k\,\beta(b)$, which is not taxed for reasons cited above. First-order conditions (9a, b, c) are unchanged, and[11]

$$u_c c_b = \lambda[(1 + t_c)c_b + f_{kc}\,\beta_b] \tag{9d}$$

$$f_{kc} = (f_v - t_v)\alpha. \tag{9e}$$

Again we solve for the Pigouvian tax rates that induce private behavior in Eqs. (9) to match the social optimum in (7). Again (7c) and (9c) imply that $\delta = \lambda$. This time, however, (7d) and (9d) can be solved for a particular value of t_c that is not zero. Then (7b) and (9b) require that $t_r = -t_c c_r$. The full set of optimizing tax rates are

$$t_c^* = -nu_B/\lambda c_b \tag{10a}$$

$$t_r^* = nu_B c_r/\lambda c_b \tag{10b}$$

$$t_g^* = n[u_B c_g - u_G c_b]/\lambda c_b \tag{10c}$$

$$t_v^* = -nu_V/\lambda. \tag{10d}$$

If illicit burning or dumping has no external effect ($u_B = 0$), then this solution reduces to the previous solution, with $t_c = t_r = 0$ and $t_g = -nu_G/\lambda$. With $u_B < 0$, however, consumption must be taxed at $t_c^* > 0$ to attain the first-best conditions, even if leisure is still untaxed. This tax is returned on goods that are properly collected as garbage or recycling. The net effect is a tax on illicit burning, circumventing the problem that b could not be taxed directly.

Garbage receives the rebate of t_c^*, but it also receives a tax that depends on its own externality. In Section 2, above, the tax was positive. Here, the net tax t_g^* is likely to be negative. In the "mass-balance" case where $c_g = c_b = 1$, garbage receives a net subsidy because u_B is more negative than u_G. In general, the tax depends on the relative ease of burning versus garbage collection (c_b versus c_g). It may also depend on the consumer's willingness to break the law. If the optimal price $p_g + t_g^*$ is *near* zero, then the city or county can save administrative and billing costs by providing free garbage collection.

Finally, the tax on virgin materials is not part of any deposit–refund system. It is not used to encourage recycled input or to discourage the generation of garbage. Instead, the tax on virgin materials should only correct negative externalities from the use of virgin materials.

4. THE UPSTREAM VS DOWNSTREAM DEBATE

This model can be used to reconcile various policy recommendations, that is, to show the conditions under which different policies can each attain the first-best allocation of resources.

---

[11] The consumer maximizes utility (2′) subject to the new budget constraint by choosing g, r, h, and b, which yields four first-order conditions in prices. We replace those prices with marginal products as before, to get (9a) through (9d). The fifth condition (9e) results directly from producer behavior; the producer of v chooses input k_v to maximize profits $p_v(\alpha k_v) - p_k k_v$, which yields $p_v = p_k/\alpha = f_{kc}/\alpha$. Then the producer of c chooses inputs k_c, r, and v to maximize profits $f(k_c, r, v) + p_r r - p_k k_c - (p_v + t_v)v$, which yields $f_v = p_v + t_v$. Thus $p_v = f_v - t_v = f_{kc}/\alpha$, to get (9e).

TABLE I

Comparison of Various Tax Schemes to Achieve the First-Best

Case 1: illicit burning or dumping cannot be taxed	Case 2: all forms of household disposal can be taxed	Case 3: no recycling subsidy (requires tax on other inputs)	Case 4: disaggregate goods (illicit dumping cannot be taxed)
$t_c^* = -nu_B/\lambda c_b$	$t_c^* = 0$	$t_c^* = nu_B c_r/\lambda c_b f_r - nu_B/\lambda c_b$	$t_{ci}^* = -nu_{Bi}/\lambda c_{bi}$
$t_r^* = nu_B c_r/\lambda c_b$	$t_r^* = 0$	$t_r^* = 0$	$t_{ri}^* = nu_{Bi} c_{ri}/\lambda c_{bi}$
$t_g^* = n(u_B c_g - u_G c_b)/\lambda c_b$	$t_g^* = -nu_G/\lambda$	$t_g^* = n(u_B c_g - u_G c_b)/\lambda c_b$	$t_{gi}^* = n(u_{Bi} c_{gi} - u_{Gi} c_{bi})/\lambda c_{bi}$
$t_v^* = -nu_V/\lambda$	$t_v^* = -nu_V/\lambda$	$t_v^* = -nu_B c_r f_{kc}/\lambda c_b f_r \alpha - nu_V/\delta$	$t_v^* = -nu_V/\lambda$
	$t_b^* = -nu_B/\lambda$	$t_{kc}^* = -nu_B c_r f_{kc}/\lambda c_b f_r$	

Note. t_c^*, t_r^*, t_g^*, and t_v^* are, respectively, tax rates on consumption, recycling, garbage, and virgin materials. t_b^* is a tax on illicit burning or dumping (only in Case 2). t_{kc}^* is a tax on resources (labor or capital) used in production of the consumption good (only in Case 3). u_G, u_B, and u_V are the (negative) externalities from garbage collection, illicit burning, and virgin material extraction. c_g, c_r, and c_b are the (positive) derivatives of $c = c(g, r, b)$, the extra consumption enabled by more g, r, or b. λ is the private marginal utility of income, and δ is the social marginal utility of income. n is the number of individuals, and i is the index for disaggregate goods and services.

The first column of Table 1 repeats the deposit–refund system just described, and the second column shows an equivalent downstream tax on wastes. In this case we constrain t_c to zero, but we allow a tax on illicit burning or dumping at rate t_b. Equations (7b) and (9b) then require $t_r = 0$, while (7d) and (9d) require the enforcement of $t_b = -nu_B/\lambda$.

Clearly the downstream tax system in column 2 can solve the problem in theory. It is the most direct policy, since the tax on each activity reflects its own externality. All tax rates are positive, but $u_B < u_G$ implies $t_b > t_g$. However, t_b would require enforcement of a tax or penalty upon actions that are easy to hide, such as burning trash in a fireplace or leaving it along a deserted road. Fortunately, the upstream tax t_c (in column 1) is easier to implement. It requires no litter penalties, and it still achieves the same first-best outcome in this model. We therefore return to the case where $t_b = 0$.

In addition, the CBO [19] echos others (e.g., [9, 14, 16]) in suggesting that a tax on virgin materials "could bring about an increase in the recycled content of some products and an overall decrease in the amount of waste disposal" [19, p. 41]. However, our equations (7e) and (9e) above show that $t_v = -nu_V/\lambda$ (as shown in columns 1 and 2 of the table). This simple Pigouvian tax only corrects for negative externalities from the extraction of virgin materials (e.g., strip mining). Some may believe that $u_V = 0$, in which case $t_v = 0$. The point is that t_v is *not* used to correct any problem related to garbage or recycling.

A reason for this nonresult is that recycling can be subsidized directly. In addition, production uses three inputs. A tax on v would encourage not only the use of r, but also the use of k_c. If recycling *cannot* be subsidized for some reason, and if k_c can be taxed at rate t_{kc}, then we can again appeal to multiple solutions. Since only relative prices matter, column 3 shows how the same first-best can be achieved using both an extra tax on virgin materials *and* a tax on k_c. In fact, the table shows that t_v and t_{kc} contain the same unambiguously positive term.[12] This term appears with the opposite sign in t_c. In other words, a subsidy for recycling in $f(k_c, r, v)$ is equivalent to a tax on v and k_c, which is then returned on output. The tax on g is unaffected.[13]

Although we show the equivalence of this result to the deposit–refund system, it is much more complicated. The tail wags the dog, since illicit dumping is corrected by multiple taxes on all inputs other than recycling, combined with a subsidy on all output.

5. DISAGGREGATE GOODS AND SERVICES

We can further modify the model to include different consumption goods c_i, where i is an index. These goods may have different technologies $c_i(g_i, r_i, b_i)$ and production functions $f_i(k_{ci}, r_i, v_i)$. Subscripts also are required for

---

[12] Slight differences appear in these terms. The tax on k_c uses $f_{kc} = \partial c/\partial k_c$ to convert to changes in c, whereas the tax on v uses $f_{kc}/\alpha = \partial c/\partial v$ to convert to changes in c.

[13] The derivation of Case 3 is a bit more difficult than the earlier cases, since λ is no longer equal to δ. We assume that p_k is the net return to individuals, so producers of c pay $p_k + t_{kc}$. Still the approach is to solve all equations (7) and (9) for t_c, t_g, t_v, and t_{kc}. Also, t_c can be manipulated to show a term $(c_r - f_r)$ which is unambiguously positive, from (7b), so t_c must be negative; the rebate of t_{kc} and t_v is within t_c, and this term exceeds the previous tax paid on c.

$u_G, u_B, \delta, t_c, t_g, t_r$, and the price of output (p). The results look exactly the same, except for the subscripts. In other words, the waste-end tax rates in column 2 must be modified to collect a specific tax rate on each good $t_{bi} = -nu_{Bi}/\lambda$, which reflects the social cost of burning or dumping that particular item. Alternatively, the deposit–refund system would collect $t_{ci} = -nu_{Bi}/\lambda c_{bi}$ on each purchase and rebate the corresponding amount upon proper disposal of that item (column 4 of Table I).

Differences arise because some goods are more toxic, more unsightly, or more easily burned. To get the details exactly right, the first-best policy would have to place a different tax rate on each item. With millions of goods and services, either of these first-best systems would be a nightmare to administer. Perhaps only some items could be targeted, or all items could be placed in just a few categories. Note, however, that this diversity among commodities is no reason to prefer waste-end taxes to the deposit–refund system: for any given commodity or category, the difficulty of enforcing a tax on illegal midnight dumping can still be avoided by taxing legal daytime purchases and subsidizing legal daytime disposal.

Consider three categories, for example. The purchase of "services" might be left untaxed, since this purchase requires no subsequent disposal.[14] A second category could receive a moderate rate, and a third, "hazardous" category would receive a higher rate. If goods with different-sized externalities were thrown into the same tax category, perhaps for reasons of administrative simplicity, then consumers would be encouraged to buy relatively too much of the goods that entailed relatively more costly disposal. Even if all goods were thrown in the same category, however, at least consumers would have some incentive to dispose of those goods properly. Results here can be taken simply to help explain existing policies that tax purchases and subsidize proper garbage collection.

6. LIMITATIONS, EXTENSIONS, AND DISCUSSION

Using broad brush strokes, this paper characterizes the optimal taxation of garbage, recycling, and general consumption. These broad strokes may miss some important details, however. One extension might consider how these optimizing fees are related to population density. We hypothesize that garbage fees would work best in suburban areas or small towns where the charges can be enforced. In densely populated urban areas, any price for garbage collection may be greeted by huge piles of unidentified garbage on the streets or vacant lots. In very rural areas, similarly, dumps may appear on back roads. Thus, these results may help explain differences in actual municipal pricing mechanisms.[15]

Another problem arises with different levels of government. States traditionally set sales tax rates, but municipal governments subsidize garbage collection. Perhaps some revenue should be transferred from one to the other. Goods may be purchased in one state, however, and then traded or carried across state lines before disposal. Various spillover effects might justify a national-level tax and

[14] On the other hand, the production of services such as legal and medical services generates plenty of paper and medical wastes. The model could be expanded to consider waste by-products from production.

[15] The U.S. EPA [10] lists sixteen towns that have unit fees for garbage collection, and we have extended that list for empirical work. All are small or moderate in size, with the exception of Seattle.

rebate system, but spillovers may still cross national boundaries. This issue deserves further scrutiny (as in Copeland [3]). Also, consideration of distributional issues might affect the optimal tax and refund system.

Finally, our model ignores some compliance costs and market imperfections. With regard to recycling, Nestor [12] points out that subsidies to households may generate supplies of recycled goods when the industrial capacity to make use of them does not exist. With regard to a per-unit garbage fee, the town would have to sell special bags or stickers. This administrative cost might further justify the subsidy inherent in free garbage collection.

None of these considerations alter our four main points, however. First, existing studies find that a negative externality from garbage can be corrected by a tax on garbage. When we add illicit dumping as a third disposal option, and assume that it cannot be taxed directly, then the tax on garbage may turn negative. Garbage collection may optimally subsidized to help prevent the worse environmental costs of improper disposal. Second, to restore all the correct relative prices, output would be taxed. The result is a deposit–refund system that is equivalent to the unenforceable waste-end tax. Third, existing literature suggests that a tax on virgin materials may help encourage recycling. In our basic model, a tax on virgin materials is not useful for that purpose. It only corrects directly for the ill effects of using virgin materials. Fourth, in existing public finance literature, a consumption tax distorts the choice between labor and leisure. This paper provides a first-best case for a consumption tax, however, even when leisure is untaxed. No tax on leisure is required, because leisure does not cause disposal problems.

APPENDIX: NOMENCLATURE

n	number of identical individuals in the single jurisdiction
c	a single composite commodity consumption good
$c(\ )$	consumption function (technology of consumption)
g	quantity of garbage collection
r	quantity of recycling
c_g	partial derivative of consumption with respect to garbage
c_r	partial derivative of consumption with respect to recycling
h	quantity of home production
G	total amount of garbage
$u(\ )$	utility function of the individual
u_c	marginal utility of consumption
u_h	marginal utility of home production
u_G	marginal utility of total garbage
$f(\ )$	production function
k_c	resources used in production of the consumption good
k_g	resources used in garbage collection
k_h	resources used in home production
γ	marginal product of resources in the collection of garbage
k	fixed total resources in the economy
$\mathscr{L}$	the Lagrange function
δ	social marginal utility of the resource (k)
f_{kc}	marginal product of the resource input (k_c)
f_r	marginal product of the recycled input
p_k	price earned on resources
t_c	tax per unit of consumption
p_g	price paid for garbage collection
t_g	tax per unit of garbage

p_r	price paid by the consumer for recycling
t_r	tax per unit of recycling
λ	private marginal utility of income
b	burning and other improper disposal
c_b	partial derivative of consumption with respect to burning
B	the total amount of burning in the economy
u_B	marginal utility of total burning
V	total amount of virgin material used in production
v	per capita virgin material used in production
u_V	marginal utility of total virgin material used in production
k_v	resources used in the extraction of virgin material
α	marginal product of resources in the extraction of virgin material
k_b	resources used in burning garbage
$\beta(\ )$	a function relating resources used in burning to the quantity of burning
β_b	the first derivative of $\beta(\ )$ with respect to burning
β_{bb}	*the second derivative of* $\beta(\ )$ *with respect to burning*
f_v	the marginal product of virgin material
p_v	price of virgin material
t_v	tax per unit of virgin material
t_b	tax per unit of burning
t_c^*	the optimal tax on consumption
t_r^*	the optimal tax on recycling
t_g^*	the optimal tax on garbage
t_v^*	the optimal tax on virgin material
t_{kc}	tax on the use of resources in the production of the consumption good
i	an index
c_i	consumption of good i
$c_i(\ )$	the consumption function for good i
g_i	garbage associated with good i
r_i	recycling associated with good i
b_i	burning associated with good i
$f_i(\ )$	the production function of good i
k_{ci}	the use of resources in the production of good i
r_i	the use of recyclables in the production of good i
v_i	the use of virgin materials in the production of good i
t_{bi}	tax on dumping for good i
u_{Bi}	the marginal utility from burning waste from good i
t_{ci}	tax on the consumption of good i
c_{bi}	the partial derivative of consumption with respect to burning

ACKNOWLEDGMENTS

This research began while both authors were at the University of Virginia. We are grateful for suggestions from Debbie Nestor, Ed Olsen, Jon Skinner, Margaret Walls, anonymous referees, and seminar participants at NBER, Carnegie Mellon, Georgia, Vanderbilt, and Virginia. We are also grateful for funding from NSF Grant SES91-22785, and from the Bankard Fund at the University of Virginia. This paper is part of NBER's research program in Public Economics. Any opinions expressed are those of the authors and not those of the National Science Foundation or the National Bureau of Economic Research.

REFERENCES

1. W. J. Baumol and W. E. Oates, "The Theory of Environmental Policy," 2nd ed., Cambridge Univ. Press, New York (1988).
2. P. Bohm, "Deposit–Refund Systems: Theory and Applications to Environmental, Conservation, and Consumer Policy," John Hopkins Univ. Press, Baltimore (1981).
3. B. R. Copeland, International trade in waste products in the presence of illegal disposal, *J. Environ. Econom. Management* **20**, March, 143–62 (1991).

4. T. M. Dinan, Economic efficiency effects of alternative policies for reducing waste disposal, *J. Environ. Econom. Management* **25**, 242–56 (1993).
5. I. M. Dobbs, Litter and waste management: Disposal taxes versus user charges, *Canad. J. Econom.* **24**, February, 221–7 (1991).
6. R. R. Jenkins, Municipal demand for solid waste disposal services: The impact of user fees, dissertation for the University of Maryland Department of Economics (1991).
7. D. R. Lee, The economics of enforcing pollution taxation, *J. Environ. Econom. Management* **11**, 147–60 (1984).
8. P. S. Menell, Beyond the throwaway society: An incentive approach to regulating municipal solid waste, *Ecology Law Quart.* **17**, 655–739 (1990).
9. A. K. Miedema, Fundamental economic comparisons of solid waste policy options, *Resour. Energy* **5**, 21–43 (1983).
10. G. E. Morris and D. M. Holthausen, The economics of household solid waste generation and disposal, *J. Environ. Econom. Management* **26**, 215–34 (1994).
11. P. A. Neher, "Natural Resources Economics: Conservation and Exploitation," Cambridge Univ. Press, New York (1990).
12. D. V. Nestor, Partial static equilibrium model of newsprint recycling, *Appl. Econom.* **24**, April, 411–7 (1992).
13. R. C. Porter, A social benefit–cost analysis of mandatory deposits on beverage containers, *J. Environ. Econom. Management* **5**, 351–75 (1978).
14. "Project 88—Round II, A Public Policy Study Sponsored by Senator T. E. Wirth and Senator J. Heinz, Directed by R. N. Stavins," Washington, DC (1991).
15. R. Repetto, R. C. Dower, R. Jenkins, and J. Geoghegan, "Green Fees: How a Tax Shift Can Work for the Environment and the Economy," World Resources Institute, Washington, DC (1992).
16. H. Sigman, A comparison of public policies for lead recycling, mimeo, UCLA Department of Economics (1991).
17. V. L. Smith, Dynamics of waste accumulation: Disposal versus recycling, *Quart. J. Econom.* **86**, November, 600–16 (1972).
18. A. M. Sullivan, Policy options for toxic disposal: Laissez-faire, subsidization, and enforcement, *J. Environ. Econom. Management* **14**, 58–71 (1987).
19. U.S. Congress, Congressional Budget Office, "Federal Options for Reducing Waste Disposal," U.S. Government Printing Office, Washington, DC (1991).
20. U.S. Environmental Protection Agency, "Charging Households for Waste Collection and Disposals: The Effects of Weight or Volume-Based Pricing on Solid Waste Management," EPA 530-SW-90-047, Washington, DC (1990).
21. K. L. Wertz, Economic factors influencing households' production of refuse, *J. Environ. Econom. Management* **2**, 263–72 (1976).