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OPTIMAL SOLID WASTE TAX POLICY WITH CENTRALIZED RECYCLING

Thomas C. Kinnaman

Economic models have demonstrated the efficiency of curbside collection taxes. This paper demonstrates that such efficiencies disappear in economies with centralized recycling options — where recyclable materials can be removed from the waste stream either by households or at a centralized recycling facility. In such economies, a curbside garbage tax not only fails to encourage the centralized recycler to internalize the external costs of waste disposal, but introduces inefficiencies to the cost-minimizing mix of household and centralized recycling efforts. The optimal waste policy is a tax assessed further downstream at the landfill rather than at the curb.

Keywords: environmental taxation, solid waste policy

JEL Codes: H2, H7, Q5

I. INTRODUCTION

Incentive-based environmental policies such as tradable permits and pollution taxes have grown in prominence over the past 25 years. Legislation to reduce lead in gasoline, to phase out CFC's, to reduce sulfur oxides, and most recently to reduce carbon dioxide in Europe have all featured tradable permits. Although certain carbon emission taxes have been enacted in British Columbia, France, and Scandinavia, curbside taxes on the collection of residential solid waste are perhaps the most common application of emission taxes. Curbside taxes have been implemented in 4,000 municipalities in the United States[1] and are also widespread in Austria, Belgium, Finland, Germany, Italy, The Netherlands, and Luxembourg. South Korea requires all of its municipalities to assess curbside fees for waste collection.

Based on efficiency arguments, economists have generally supported the implementation of such curbside taxes for households to internalize all costs of disposing their waste (Repetto et al., 1992; Miranda et al., 1994; Porter, 2002). Such fees encourage

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[1] See "Unit-Based Pricing in the United States: A Tally of Communities." United States Environmental Protection Agency, http://www.epa.gov/waste/conserve/tools/payt/states/comminfo.htm.

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households to recycle optimally and thus reduce waste efficiently without facing behavioral mandates. Residential waste has been estimated to decrease by two to15 pounds-per-household per week in response to a curbside tax of $1 per 30-gallon can.[2] Possible increases in illegal dumping (Fullerton and Kinnaman, 1995; Kim, Chang and Kelleher, 2008) and the high administrative costs of assessing curbside taxes (Kinnaman, 2006) are potential drawbacks of curbside taxation.

This paper suggests a third possible problem with curbside waste taxes. Such taxes are found to introduce two inefficiencies in an economy endowed with technologies to separate recyclable materials from the general waste stream at a centralized separating facility. First, curbside taxes distort the cost-minimizing mix of recycling efforts between individual households and centralized facilities. Second, curbside taxes do not create price incentives for centralized recycling facilities to internalize the external costs of waste disposal. The previous literature assumed that only households possessed technologies for separating recyclable materials from the mixed waste stream.

The model below will demonstrate that the optimal policy in an economy with centralized recycling options is a tax assessed not at the curb but further down the waste stream at the landfill. The landfill tax encourage centralized recyclers to make efficient decisions regarding the amount to remove from the waste stream and allows for vertical equality of marginal costs between household and centralized recycling efforts. The other advantage of the landfill tax, as is the case with the curbside tax in economies without centralized recycling, is the elimination of all other policies designed to alter household disposal decisions such as mandatory recycling laws, deposit-refund systems, and banning materials from landfills. One tax does the job.

Centralized recycling technologies are utilized in many parts of the developed world, especially in Japan and portions of northern Europe and the United States. Labor-intensive versions of a centralized recycling system feature workers extracting recyclable materials by hand from a slow moving conveyor belt. Capital intensive versions include the use of magnets to extract ferrous metals, air classifiers with blowers to separate light plastics, and eddy-current separators with magnets to push aluminum into separation bins. According to a national survey of randomly selected municipal recycling programs conducted in 1997 and described in Folz (1999), roughly 44 percent of municipalities in the sample separate recyclable materials in centralized facilities. These municipalities recycle an average of 18.6 percent of their waste materials, slightly higher than the 15.5 percent recycling rate reported by municipalities without centralized recycling facilities. As labor costs rise and separation technologies improve, the portion of household materials separated for recycling at centralized facilities may increase in the future.

Sections II and III of this paper present the economic model of the waste market with and without centralized recycling. Section IV discusses the empirical implications of the model, and is followed by a short conclusion.

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[2] Kinnaman (2006) and the references therein summarize the empirical estimates. For perspective, the average household generates roughly 50 pounds of waste per week in the absence of curbside taxation.

II. NO CENTRALIZED RECYCLING

To introduce notation and characterize prior results, this section develops a model where only households possess recycling technologies as a centralized recycling option does not exist. Assume a representative household gains utility (u) from its own consumption of a composite commodity good (c) and experiences disutility from the aggregate quantity of disposed waste (D),

(1) $u = u(c, D)$, where $u_c > 0$ and $u_D < 0$.

Each unit of consumption (c) generates one unit of waste. Each unit of waste can either be separated by the household for curbside recycling collection (r) or remain in a mixed state (m) for collection and disposal in a landfill. Thus,

(2) $c = r + m$.

Separating waste materials for recycling requires the employment of a household resource such as labor (k^h) according to the household recycling production function $r = \sigma(k^h)$, where $\sigma' > 0$ and $\sigma'' < 0$. This function can be inverted to explicitly solve for k^h

(3) $k^h = h(r)$, where $h' > 0$ and $h'' > 0$.

A representative waste collection firm employs labor to remove separated waste (requiring k^r) and mixed waste (requiring k^m) according to the inverted production functions[3]

(4a) $k^r = r(r)$, where $r' > 0$ and $r'' > 0$

(4b) $k^m = m\ (m)$, where $m' > 0$ and $m'' > 0$.

A representative production firm uses labor (k^c) and recycled waste materials (r) to produce the composite commodity good according to the production function

(5) $c = f(k^c, r)$, where, $f_k > 0, f_r > 0, f_{kk} < 0$, and $f_{rr} < 0$.

In this version of the model, all mixed waste collected from households is disposed at a landfill (d), thus $m = d$. The landfill uses labor in the disposal process.

(6) $k^d = d(d)$, where $d' > 0$ and $d'' > 0$.

The aggregate quantity of waste is $D = nd$, where n is the number of representative households in the economy. Labor is fully employed at a fixed $\bar{k}$ (thus assuming no choice over labor and leisure), thus

(7) $\bar{k} = k^h + k^r + k^m + k^c + k^d$.

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[3] These production functions could involve either a constant or decreasing marginal product of labor to achieve the market equilibriums discussed below.

A. Social Planner

A social planner maximizes household utility (1) subject to constraints (2) through (7), $m = d$, and $D = nd$. Upon substitution, the planner chooses the quantity of separated household waste (r) and disposed waste (d) to maximize

$$\mathcal{L} = u(r + d, nd) + \lambda\{f[\bar{k} - h(r) - r(r) - m(d) - d(d), r] - r - d\},$$

where λ is the marginal utility of increasing the production of the composite commodity good. The first-order conditions are[4]

$$\text{(8a)} \quad \mathcal{L}_r\text{: } u_c/\lambda = f_k h' + f_k r' - f_r + 1$$

$$\text{(8b)} \quad \mathcal{L}_d\text{: } u_c/\lambda = f_k m' + f_k d' + 1 - nu_D/\lambda.$$

Setting these two conditions equal to each other and simplifying implies the socially optimal allocation of waste and recycling can be characterized by the marginal condition

$$\text{(9)} \quad m' + d' - nu_D/\lambda f_k = h' + r' - f_r/f_k.$$

Optimality requires the full social marginal cost of waste disposal to be equal to the full social marginal cost of recycling. The full social marginal cost of waste disposal is comprised of the marginal cost to collect the waste (m'), the marginal cost to dispose of the waste (d'), and the household disutility experienced from all disposed waste (measured in units of labor per unit of waste disposal). The marginal cost of recycling is comprised of the marginal cost for the household to separate the waste (h') plus the marginal cost to the waste company to collect the separated material (r') less the productive benefit of the recycled material in producing the composite commodity good. The next section explores the conditions necessary for a decentralized economy to obtain this social optimum.

B. Decentralized Competitive Economy

Assume both a curbside disposal tax (t_m) and landfill tax (t_d) are available to social planners to enable waste generators to internalize the social costs of disposal. Each representative household in a decentralized market economy maximizes its own utility (1) subject to the materials balance constraint (2), the household separating production function (3) and the budget constraint.

$$(\bar{k} - k^h)w + p_r r = c + (p_m + t_m)m.$$

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[4] A unique solution is assumed to be internal and second-order conditions are assumed to hold (Baumol and Oates, 1988).

The household earns income from allocating its endowment of labor (less that used to separate recyclable materials) to the labor market in exchange for wage w and revenue earned from the curbside collection of their separated recycled materials (p_r, which can be negative if separated materials have no economic value to producers of the composite good). The household spends this income on the composite good (the numeraire good with price $p_c = 1$ per unit) and for the collection of mixed waste (p_m per unit plus the curbside disposal tax t_m).

Because n is large, each representative household does not internalize the externality associated with its own waste generation, and instead considers D to be exogenously determined. The household chooses the quantity of their waste to separate for recycling (r) and the quantity to remain mixed (m) to maximize

$$\mathcal{L} = u(r + m, D) + \delta\,[w\bar{k} - wh(r) + p_r r - (r + m) - (p_m + t_m)m]\ ,$$

where δ is the marginal utility of household income. The first-order conditions are

$$\mathcal{L}_r\colon\ u_c/\delta = wh' - p_r + 1$$

$$\mathcal{L}_m\colon\ u_c/\delta = 1 + p_m + t_m.$$

Combining these, the household maximizes utility by satisfying the marginal condition

$$(10)\quad wh' = p_r + p_m + t_m.$$

The household devotes resources to recycling until the marginal opportunity cost (wh') is equal to the marginal benefit — the price received for separated materials plus the after tax savings from not disposing those materials as waste.

A waste collection firm earns revenue from collecting mixed waste from households (at p_m per unit) and from selling separated materials to the producers of the composite good (at price p_s). Costs are comprised of payments to households for collecting separated recycled materials (p_r, which once again can be negative), payment to landfills for waste disposal (at p_d per unit disposed), and costs to employ labor to collect both separated and mixed wastes at the curb

$$\pi = p_m m + p_s r - p_r r - p_d m - wr(r) - wm(m).$$

Profit is maximized by choosing the amount of mixed waste (m) and recycled waste (r) to collect subject to the production functions (4a) and (4b), and the constraint that $m = d$ (all collected mixed waste is disposed at the landfill). The first-order conditions are

$$(11a)\quad \pi_m\colon\ wm' = p_m - p_d$$

$$(11b)\quad \pi_r\colon\ wr' = p_s - p_r.$$

The collector chooses quantities such that the marginal cost of collecting mixed and separated waste equal their respective marginal benefits.

The producer of the composite commodity good earns revenue from the sale of the numeraire composite good (c with price equal to 1), pays w for each unit of labor (k^c), and pays the collector for separated recyclable materials (p_s). It maximizes profit

$$\pi = c - wk^c - p_s r$$

subject to the production function (5) by setting $f_k = w$ and $f_r = p_s$. Combining these conditions yields

$$(12) \quad f_k / w = f_r / p_s.$$

Profit is maximized by choosing inputs such that the ratios of the marginal product and the marginal cost of each input are equal.

Finally, the landfill operator chooses the quantity of mixed waste ($m = d$) to accept for disposal to maximize profit

$$\pi = (p_d - t_d)d - wk^d,$$

subject to the production function (6). The waste disposal firm pays a tax on each unit of waste accepted for disposal (t_d). Profit is maximized when

$$(13) \quad wd' = p_d - t_d.$$

Substituting (11a) and (11b) into (10) to eliminate p_m and p_r and then substituting (12) and (13) into the resulting equation to eliminate p_s and p_d yields

$$(14) \quad m' + d' + (t_m/w + t_d/w) = h' + r' - f_r/f_k.$$

The social optimum can be achieved in the decentralized economy by setting the garbage collection tax (t_m) and/or the landfill tax (t_d) such that (14) is identical to (9). The optimal tax policy, upon substituting $f_k = w$ from the producer's profit-maximization problem above satisfies the condition

$$(15) \quad t^*_m + t^*_d = -nu_D/\lambda.$$

A tax of $-nu_D/\lambda$ can be assessed at the curb ($t_m > 0$, $t_d = 0$), at the landfill ($t_m = 0$, $t_d > 0$), or any linear combination of the two taxes such that (15) is satisfied. If administrative costs are associated with implementing either tax, then the optimal policy would involve selecting the single tax (t_m or t_d) that involves the fewest administrative costs. Because the number of households far exceeds the number of landfills, administrative costs may be lower for the landfill tax than the curbside tax. Otherwise, there is nothing in the model to support favoring one tax approach over the other.

Controlling for changes in notation and a few other details of this model, the curbside tax rate ($t_m > 0$, $t_d = 0$) is similar to optimal tax rates found in the existing literature — a literature that does not consider landfill taxation.[5] The magnitude of the optimal tax increases with the magnitude of the externality (nu_D, which is negative), and decreases with increases in the marginal utility of production (λ).[6]

III. HOUSEHOLD AND CENTRALIZED SEPARATION OPTIONS

Assume now that the representative waste collecting firm employs labor (k^s) and a technology to separate household waste (m) for recycling at a centralized recycling facility (with quantity s) according to the inverted production function

(16) $k^s = s(s)$, where $s' > 0$ and $s'' > 0$.

The remainder of the mixed waste is taken to the landfill. Thus, instead of $m = d$, we have

(17) $m = s + d$.

A. Social Optimum

The social planner chooses r, d, and s to maximize utility (1) subject to constraints (2) through (7), where (7) now includes k^s, the requirement that $D = nd$, and (16) and (17). The Lagrange function is

$$\mathcal{L} = u(r + s + d, nd) + \lambda\{f[\bar{k} - h(r) - r(r) - m(s + d) - s(s) - d\,(d), r + s] - r - s - d\},$$

where λ once again is the marginal utility of producing one additional unit of the composite commodity good. The first-order conditions are

(18a=8a) $\mathcal{L}_r$: $u_c/\lambda = f_k h' + f_k r' - f_r + 1$

(18b=8b) $\mathcal{L}_d$: $u_c/\lambda = f_k m' + f_k d' + 1 - nu_D/\lambda$

(18c) $\mathcal{L}_s$: $u_c/\lambda = f_k s' + f_k m' - f_r + 1$.

The first and second conditions are identical to those above. Combining (18a) and (18b) to eliminate u_c/λ yields the same marginal condition given in (9) above, which

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[5] This literature includes Miedema (1983), Dobbs (1991), Dinan (1993), Palmer and Walls (1994), Fullerton and Kinnaman (1995), and most recently Ferrara (2008).

[6] This model does not include virgin materials as a substitute in production for recycled materials. Fullerton and Kinnaman (1995) demonstrate that the addition of virgin materials to a general equilibrium model does not alter the optimal tax rate for waste.

is restated as (19a) below. Combining (18a) and (18c), and then (18b) and (18c) yields two additional conditions for the social optimum

$$(19a{=}9)\quad m' + d' - nu_D/\lambda f_k = h' + r' - f_r/f_k$$

$$(19b)\quad h' + r' = m' + s'$$

$$(19c)\quad s' - f_r/f_k = d' - nu_D/\lambda f_k.$$

As above, optimality condition (19a) equates the full social marginal costs of curbside waste disposal and curbside recycling. Condition (19b) equates the full marginal cost of household recycling and the full marginal cost of centralized recycling. The former is comprised of the marginal cost to the household to separate the waste (h') plus the marginal cost to the waste collector to collect the separated waste (r'). The latter is comprised of the marginal cost to the collector to collect mixed waste (m') plus the marginal cost to separate that waste at the centralized recycling facility (s'). The final optimality condition (19c) equates the full social marginal cost of recycling the material at the centralized facility with the full social marginal cost of disposing the material. Centralized recycling incurs a marginal cost (s') but generates raw materials for production (f_r/f_k). Disposal involves a marginal cost (d') and a direct loss in household utility.

B. Decentralized Competitive Equilibrium

The optimal tax policy now has to satisfy three conditions, rather than just one. Consider once again the two tax policies available to policy makers to allow decentralized economic agents to reach the social optimum, a curbside tax on waste collection (t_m) and a waste tax levied at the landfill (t_d).

The household faces the identical problem as above and therefore maximizes utility according to (10). The household separates waste until the marginal resource cost is equal to the curbside (after tax) price of waste plus the price received for recycled materials.[7] Likewise the profit maximizing behavior of the firm producing the composite good is identical to the conditions given in (12) above. The landfill also faces the same problem as above and maximizes profit when (13) is satisfied.

The waste collector/processor once again earns revenue from selling recycled materials (at price p_s) to the representative producer. But the recycled materials are now separated either by the household (r) or the centralized recycling facility (s), and are assumed to be perfect substitutes in the production of the composite good. As above, the waste

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[7] Notice private waste haulers may choose to charge households a positive market per-bag price at the curb for waste collection if $p_m > 0$. The implication of the private decision to charge a monthly fee ($p_m = 0$) or a per-bag fee ($p_m > 0$) on efficient outcomes is discussed in the next section below.

collector/processor earns revenue from collecting mixed waste from the household (p_m), pays p_r to the household for separated waste (r), pays the landfill p_d to dispose non-separated waste (d), and pays w for labor to collect mixed waste (k_m), to collect separated waste (k_r) and now to separate waste at the centralized recycling facility (k_p). The waste collector's problem is to maximize profit

$$\pi = p_s(r + s) + p_m(d + s) - p_r r - p_d d - wr(r) - wm(d + s) - ws(s),$$

where $m = d + s$. The first order conditions are now

(20a=11a) π_d: $wm' = p_m - p_d$

(20b=11b) π_r: $wr' = p_s - p_r$

(20c) π_s: $wm' + ws' = p_s + p_m$.

The first two of these conditions are identical to the profit-maximizing conditions above. The third condition suggests the collector/processor separates mixed waste (m) and the centralized recycling facility such that the marginal cost (wm' to collect the mixed waste plus ws' to separate the mixed waste) is equal to the marginal revenue (the price paid by producers for the separated materials plus the price paid by household to collect mixed waste).

The decentralized equilibrium is completely represented by (10), (12), (13), and (20a-20c). Upon substitution, this system of six equations is reduced to

(21a) $wh' + wr' = p_m + wf_r/f_k + t_m$

(21b) $wm' + wd' = p_m - t_d$

(21c) $wm' + ws' = p_m + wf_r/f_k$.

Combining first (21a) and (21b), then (21a) and (21c) and finally (21b) and (21c) to eliminate p_m yields the three conditions

(22a) $m' + d' + t_d/w + t_m/w = h' + r' - f_r/f_k$

(22b) $h' + r' = m' + s' + t_m/w$

(22c) $s' - f_r/f_k = d' + t_d/w$.

The social optimum is achieved when these three conditions are equivalent to (19a), (19b), and (19c). Two tax instruments, t_m and t_d, are once again available.

C. The Landfill Tax ($t_d > 0, t_m = 0$)

Consider a tax levied not at the curb, but at the landfill. The single landfill tax can achieve all three of the optimal marginal conditions defined above. To see this, first compare (19a) and (22a). The optimal tax is

$$(23) \quad t_d^* = -nu_D / \lambda ,$$

which is the same tax rate assessed at the landfill in an economy without centralized recycling technology (in Section II above). Even though the household does not explicitly pay a curbside tax, the optimal landfill tax may cause the collector/processor to increase the curbside price of waste collection, a decision examined in Section IV below.

Next, compare (19b) and (22b) and note that the decentralized equilibrium satisfies the optimality condition. The landfill tax does not appear in this condition, and thus a positive landfill tax does not distort the waste collector/processor's efficient decision between collecting separated waste from households and separating the waste themselves. This decision is instead governed in a decentralized economy by the marginal costs of each option.

Finally, compare (19c) and (22c) and note that the tax necessary to achieve optimal condition (22c) is once again the optimal tax rate given in (23). A single landfill tax encourages both the optimal recycle/landfill decisions by collector/processors and optimal separating decisions by households. The landfill tax causes waste collecting/processing firms to internalize the social costs of landfill disposal while at the same time causing those firms to increase the price of collecting non-separated waste from households.

D. The Curbside Waste Tax ($t_m > 0, t_d = 0$)

Recall that the existing economic literature suggests a curbside waste tax (t_m) allows a decentralized economy to achieve the efficient allocation of resources when illegal dumping is not a factor. The optimal curbside tax of $t_m^* = -nu_D/\lambda$ is necessary for (22a) to equal (19a). The waste-producing household internalizes the waste externality and accordingly chooses the optimal quantities of mixed and separated waste.

But the social optimum condition (19b) can only be satisfied when $t_m = 0$. Profit maximizing collectors/recyclers choose between household and centralized separation methods and reach equilibrium when the marginal costs of both options are equal. A positive curbside tax distorts this equilibrium and causes households to inefficiently separate waste that could be separated at the processing facility at lower cost. In the long run, the curbside tax could delay the natural development of a centralized recycling industry because the tax reduces the recycled materials available in mixed waste streams.

Once mixed materials have been collected from households, optimality condition (19c) implies the marginal cost of separating materials at the centralized facility should be equal to the marginal social cost of disposal. A curbside waste tax is powerless to internalize disposal costs to centralized recyclers (it does not appear in (22c)), and therefore a policy approach relying only on curbside taxes yields too little centralized recycling and too much disposal.

To summarize, although the curbside waste tax induces *households* to make efficient waste disposal decisions, two inefficiencies are introduced with centralized recycling. First, curbside taxes unnecessarily distort the process of material separation in favor of households over centralized recyclers. Second, curbside taxes are too far upstream to internalize the social costs of disposal for centralized recycling firms.

E. Both Tax Policies ($t_m > 0, t_d > 0$)

Recall in Section II above that any linear combination of the two available tax policies satisfying (15) leads to the efficient quantities of waste and recycling. This result does not carry through to the case of centralized recycling. The curbside tax (t_m) *must* be zero for the full marginal cost of household recycling to equal the full marginal cost of centralized recycling. Furthermore the landfill tax (t_d) must alone equal the left hand side of (15) to equate the full social marginal cost of recycling the material at the centralized facility with the full social marginal cost of disposing the material. Curbside taxes must therefore be zero and landfill taxes set equal to the full external costs of waste in economies with centralized recycling technologies.

IV. EMPIRICAL IMPLICATIONS OF THE MODEL

The optimal tax rate on waste disposed at the landfill as modeled above is equal to the external marginal cost of waste collection and disposal ($-nu_D/\lambda$). External costs of waste collection include road congestion and the increased likelihood of vehicle accidents from waste trucks. Waste disposed in landfills can cause odor and unsightliness, threaten local ground water supplies, and contribute to climate change by emitting methane. Incinerators also release climate change gases, diminish local air quality, and generate hazardous ashes.

A few economic papers have estimated these external costs. Dijkgraaf and Vollebergh (2004), for example, estimate that external costs are \$4.87 per ton for landfill disposal and \$20.58 per ton for incineration.[8] Kinnaman (2006) estimates external costs at \$5.76–\$9.38 per ton of waste disposed at landfills, where the higher value pertains to remote rural landfills that require lengthy transportation routes and to landfills that do not capture methane for electricity production. Isely and Lowen (2007) estimate external costs at \$5.48 per ton for landfill disposal. Of these three, only the Kinnaman (2006) estimate includes the external costs of waste transportation — estimated at 58 cents to \$1.93 per ton (Davies and Doble, 2004). Based upon these three estimates, the optimal landfill tax appears to fall in the \$5–10 per ton range. The optimal incineration tax could be over \$20 per ton.

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[8] All estimated external costs cited in this paragraph have been adjusted to 2010 dollars.

Landfill taxes are common in many parts of the developed world. In the United States, the Resource Conservation and Recovery Act (RCRA) of 1976 allocated to the individual states the authority to regulate solid waste. Twenty states have implemented landfill taxes ranging from 25 cents per ton in Hawaii to $8 per ton in New Jersey (Kinnaman, 2006). Landfill taxes in the United States average $2.22 per ton — a bit lower than the estimated external marginal costs of waste collection and disposal cited above. Internationally, the United Kingdom, The Netherlands, France, and Sweden have also implemented landfill taxes.

Recall that the landfill or incineration tax, if set at an efficient level, internalizes all costs of disposal, and all other policies designated to promote recycling or discourage waste are unnecessary and produce inefficiencies. In virtually all cases of existing landfill taxes, both internationally and in the United States, governments have also imposed an assortment of other policies such as mandatory recycling ordinances, required recycled content standards in production, an assortment of subsidies to promote recycling, producer responsibility laws, and deposit-refund schemes. These additional policy measures are unnecessary if landfill taxes are set efficiently.

To advocates of curbside waste pricing, an interesting empirical question is whether or not the implementation of a landfill tax will affect a local garbage collector's curbside pricing strategy. Two broad pricing options are available. First, a collector can charge households a flat fee for unlimited use of its waste collection services. Under this pricing scheme, the marginal cost to the household of contributing an additional unit of waste is zero ($p_m = 0$). Or the collector can instead measure the household's waste and charge according to the weight or volume ($p_m > 0$). The profit-maximizing waste collector selects unit pricing over the flat fee only if the private benefits of doing so exceed the private costs.

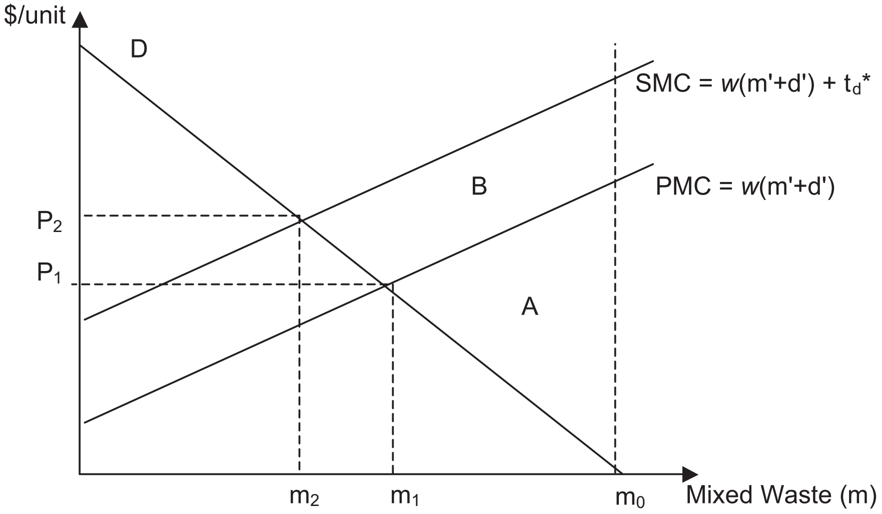
The private benefits of employing unit pricing ($p_m > 0$) are illustrated in Figure 1, where the quantity of mixed waste collected is measured along the horizontal axis. Household demand for collection services is derived from the consumption it supports, and is labeled D in Figure 1. The private marginal cost (PMC) of waste collection and disposal is, by the assumptions of the model above, equal to $w(w' + d')$. Because of assumed diminishing marginal returns in these two production processes, both m' and d' increase with the quantity of waste collected. Households generate m_0 units in response to a fixed monthly fee ($p_m = 0$). The market-equilibrium curbside price of p_1 reduces the quantity of waste generated by households from m_0 to m_1. The private benefit to the waste collector/processor from charging this price is illustrated by area A in Figure 1.

But to capture these benefits, collection/processor firms must develop a technology to monitor each household's unique waste contribution. Options could include universal product codes on waste containers, fitting scales on garbage trucks to weigh garbage, or issuing special bags, stickers, or tags to each household. Collectors must also take the time to monitor each household's waste contribution, and in some cases individualized bills must be sent to each customer. Assume the administrative cost of these efforts is TC. The profit-maximizing waste collector will adopt unit pricing only if $A > TC$. The outcome of this condition could vary across municipalities.

The implementation of the optimal landfill tax increases the private marginal cost of waste collection and disposal. The optimal price for waste collection increases from p_1

Figure 1

The Total Benefits of Curbside Pricing



to p_2, household waste generation decreases from m_1 to m_2, and the benefits of implementing unit pricing to the collector increase from area A to area $A + B$. The landfill tax will encourage the collector/processor to implement curbside pricing if $A + B > TC > A$. Fixed monthly fees will be levied under a landfill tax if $A + B < TC$. Because the collector/processor paying the landfill tax internalizes all social benefits and administrative costs of each pricing strategy, its profit-maximizing decisions will be efficient. The lack of a curbside price is not evidence of inefficient pricing policies or of market failure.

The empirical economics literature has estimated this effect — how an increase in landfill disposal costs (tipping fees) affect the likelihood of adopting curbside pricing strategies. Kinnaman and Fullerton (2000) estimate that a $1 per ton increase in landfill disposal costs increases the probability a local waste collector implements per-bag pricing by only 0.78 percent. Extrapolating from those results, a $10 increase in landfill disposal fees (the upper bound of the estimates of external marginal cost of waste collection and disposal) increases the likelihood of per-bag pricing by 7.8 percent. Among those localities that have implemented per-bag pricing, Kinnaman and Fullerton (2000) find a $1 increase in landfill disposal costs increases the curbside fee by 3.5 cents per bag — suggesting a $10 increase would increase curbside fees by 35 cents per bag. Tawil (1995) also estimates the probability of adopting curbside pricing increases with economic variables such as disposal fees.[9]

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[9] In a related question, Kinnaman (2006) finds no empirical relationship between the landfill cost of disposal and the likelihood that local collectors offer curbside recycling to households.

A final empirical question is the effect of a positive curbside price on household disposal behavior. In response to a curbside price of \$1 per 30-gallon bag, existing estimates suggest that households reduce garbage by between one to 10 pounds per week — roughly 2–20 percent of a household's waste (Kinnaman, 2006). Fullerton and Kinnaman (1996) estimate that 28 percent of the reduction of garbage observed at the curb from the implementation of curbside pricing may be redirected to illicit or illegal forms of disposal.

V. CONCLUSION

The states of Wisconsin and Washington require their municipalities to implement curbside taxes, and internationally South Korea requires all municipalities to implement curbside taxes. The model presented in this paper suggests landfill and incineration taxes should replace such local curbside taxes when centralized recycling technologies are available. Where centralized recycling technologies do not exist, the landfill tax preserves the efficiency properties of the curbside tax and removes a barrier to the eventual emergence of centralized recycling facilities. Local waste collectors may choose to price garbage at the curb if the benefits of doing so exceed the costs.

The conclusions of the model can easily be extended to demonstrate that other solid waste policies directed at households are also inefficient with centralized recycling technologies. For example, much of the economics literature on optimal waste policy cited above advocates deposit-refund programs where households face opportunities for illegal dumping. As is the case with the curbside tax, the efficiency of deposit-refund programs where refunds for recyclable materials are paid directly to households is preserved only in economies with no centralized recycling technologies. With centralized recycling programs, refunds must be paid to centralized recyclers to avoid the two inefficiencies discussed above. Centralized recyclers internalize the social costs of disposal with the recycling refund and the optimal allocation of separation efforts between households and centralized recyclers is preserved.

Finally, many municipalities, both internationally and in the United States, collect household mixed waste and separated recyclable materials using public municipal resources. In principle, the landfill tax causes public agencies to internalize the social costs of landfill disposal as described above. However, the likelihood that the landfill tax would lead to optimal curbside pricing following the logic of Figure 1 would be reduced if the public agency pursues goals other than cost minimization.

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