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Economic Efficiency Effects of Alternative Policies for Reducing Waste Disposal[1]

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Reducing the amount of municipal solid waste that is disposed of has become an important policy goal. Previous research argued that a virgin material tax offered an efficient method of meeting this goal and it continues to be considered as a policy option today. This paper demonstrates, however, that a virgin material tax is not an efficient method of reducing waste, but that an alternative policy—a combined disposal tax and reuse subsidy—is. The combined disposal tax and reuse subsidy is theoretically consistent with unit-based household charges for waste disposal, but may have advantages in some situations.

I. INTRODUCTION

The United States Environmental Protection Agency (EPA) estimates that Americans generated 180 million tons of waste in 1988 and that quantity is expected to increase to over 199 million tons annually by 1995 [16]. Concern about potential environmental hazards associated with disposal[2] has led to strong resistance to the siting of new facilities and the adoption of expensive environmental safeguards on facilities that are sited. These two factors have greatly increased the cost of waste disposal and led to public interest in decreasing the amount of waste that is generated and increasing the amount that is diverted for recycling.

While decreasing disposal may reduce costs for the community as a whole, individual households lack a financial incentive to decrease the amount of waste that they generate. Households currently pay for waste disposal primarily through their local taxes or by fixed fees paid to private collectors. Under this system of payment, households lacks a financial incentive to consider disposal costs in their purchasing and recycling decisions.[3] This, in turn, does not provide producers with an adequate incentive to produce goods that are less costly to dispose of or to use recycled materials in their production processes.

A direct method of correcting this market failure, of course, would be to charge households according to the amount of waste that they generate (referred to here as unit-based pricing). While this solution has some potential, it provides incen-

[1]The views expressed here are those of the author and should not be attributed to the Congressional Budget Office. I am grateful for helpful comments provided by LeRoy Hansen, Patrice Gordon, Roger Hitchner, and two anonymous reviewers, but assume responsibility for all remaining errors.

[2]According to the EPA, there are 214 sites containing municipal solid waste on the National Priority List—a list of the nations worst abandoned hazardous waste sites [8].

[3]There may be some minor income effect as fixed fees or property taxes account for a larger share of household's budgets.

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tives for illegal disposal and can be difficult to administer correctly (see Section VII).

This paper demonstrates that an efficient level of waste disposal may be obtained by an alternative approach. This approach utilizes a combination of a tax on producers of goods that may ultimately be disposed of and a subsidy for end users of recycled materials. As discussed below, a combined disposal tax and reuse subsidy can provide signals for an efficient level of waste disposal and has advantages over unit-based pricing in some situations.

Unfortunately, previous analyses of inefficiencies related to solid waste management have included discussions of policies that create a bias toward the use of virgin materials, such as preferential tax policies, below cost timbers sales, and mineral rights policies (for example, see [3, 17]). Although inefficiencies in the pricing of virgin materials and disposal services have inter-related implications (e.g., elimination of virgin material biases may lead to increased use of recycled materials and proper pricing of disposal services may lead to less use of virgin materials), they are distinct problems that call for different solutions.

The linking of these two problems has led to the proposal of virgin material fees as a method of promoting efficient waste disposal and recycling practices. Two bills introduced in Congress in recent years have proposed that fees be levied on the virgin content of plastics, paper products and/or packaging materials (materials which are targeted as large-volume and/or unessential items in the solid waste stream).[4] In addition, Miedema [6] advocates virgin material fees as an efficient method of encouraging recycling and reducing the disposal of beverage containers (further discussed below).

Virgin material fees can, in fact, increase the demand for recycled materials and hence reduce disposal requirements. In addition, they may raise prices of recycled materials, an outcome that might be desired by communities seeking to increase their recycling rates. It is important, however, to recognize the important drawbacks in terms of efficiency associated with using virgin material fees as a means of reducing disposal requirements. This article reveals those limitations.

This paper examines the production of two goods and determines the "optimal" levels of production, selections of inputs, and number of firms in each industry that would result if disposal costs were internalized. It then demonstrates that a virgin material tax cannot result in this optimal resource allocation but that a combined disposal tax and reuse subsidy policy can. While a combined tax and subsidy policy is not currently under consideration at the federal level, this type of policy is being used to encourage the recycling of old tires in Idaho [11].

II. COMPARISON WITH PREVIOUS WORK

Surprisingly little has been written on policies that will provide efficient incentives for waste disposal. Several authors have examined the use of volume (or weight)-based disposal fees for households as a means of bringing about the efficient level of waste disposal (see [7, 9]). This article does not refute this work, but rather, offers an alternative policy that is theoretically consistent and has

[4]See S.2774 of the 100th Congress and H.R.3737 of the 101st Congress. Under both bills, the revenues would be dedicated toward providing funds for solid waste planning.

advantages in some situations. The similarities and differences between the combined disposal tax and reuse subsidy described in this article and unit-based pricing are described in Section VII.

As described above, Miedema [6] advocates virgin material fees as a means of motivating efficient waste disposal practices. My work contradicts this finding. At first glance, Miedema's work might not seem comparable with this article since his analysis purports to address two inefficiencies associated with waste disposal. He argues that in addition to the problems caused by flat-fee pricing, the "indirect subsidization" of virgin materials is a second inefficiency. This indirect subsidization is "the market's failure to incorporate the eventual collection and disposal costs of some virgin materials in their prices. By comparison, not only do recyclable materials prices include collection costs, but also their use avoids disposal costs... Supposedly, this simultaneously induces excessive use of underpriced materials, and hence excessive generation of wastes, while inhibiting the use of recyclables" (p. 22).[5]

My contention, however, is that the indirect subsidization of virgin materials is not a separate inefficiency, but rather a direct result of flat-fee pricing. To see this most clearly, consider the case in which flat-fee pricing was eliminated; that is, all households paid for disposal based on the volume of the waste that they disposed. In this case, virgin materials that were incorporated into products and subsequently recycled (e.g., wood made into a newspaper that was then recycled) would avoid the disposal cost. Virgin materials that were incorporated into products and subsequently disposed would bear the disposal cost. As in any economic system, a failure in one market affects related markets, but it is a mistake to treat these distortions as independent market failures. If one were to view the indirect subsidy of virgin materials as a separate inefficiency and seek to correct both inefficiencies (i.e., have volume-based pricing and disposal fees on virgin materials) then virgin materials would be penalized beyond an efficient point (i.e., once when used in production and once when disposed.

In addition to the issue of the indirect subsidization of virgin materials, a crucial assumption that Miedema's results depend on is that all recyling is closed loop—that is, recycled materials are used back into their original products and, therefore, always displace virgin materials. Specifically, in Miedema's model old beverage containers are recycled into new beverage containers, replacing virgin material. In reality, however, there are several significant recycling options that do not replace virgin materials. As demonstrated in this article, the failure of a virgin material tax to encourage these end uses causes the virgin material tax to be an inefficient method of reducing waste disposal.

The Tellus Institute [14] analyzes a disposal fee proposed for the state of California. This fee is a weighted average of the cost of recycling and the cost of disposing of each material; the weights are based on the average recycling rate for that material in California.[6] This system is acknowledged by the authors as a compromise between the goals of encouraging "source reduction," which is making

[5]Virgin material-biased tax policies and regulations may also lead to the inefficient use of virgin materials; however, these are excluded from Miedema's analysis.

[6]The Tellus Institute study also differs from this analysis in that they attempt to internalize the cost of recycling as well as the cost of disposal. Since a market exists for recycled materials, however, it seems reasonable to assume that the cost of recycling is included in the prices that these materials are exchanged at and, therefore, is internalized.

the good less waste intensive (e.g, printing fewer pages in the Sunday paper), and encouraging recycling (pp. 7–12). The combined disposal tax and reuse subsidy described in this article avoids the need for such a compromise by employing two separate policy instruments. The disposal tax provides an efficient signal for source reduction and the reuse subsidy provides an incentive to use an efficient amount of recycled materials.

III. RESOURCE USE UNDER THE SOCIALLY OPTIMAL SOLUTION

In order to demonstrate the conditions that are necessary to maximize social welfare, the optimal production levels and input choice for two goods in time period t are examined—newspapers, Q, and "an other" good X. Both of these goods may use old newspapers as an input in production. It is assumed that each newspaper that is disposed results in a cost, d_t, where d_t includes all costs associated with its disposal, including external costs and depletion costs associated with using up scarce landfill capacity. It is assumed that consumption of the other good does not result in any disposal costs.[7] This discussion parallels an examination of socially optimal pollution levels by Spulber [10], but is tailored to the specifics of the newspaper production and disposal and is expanded to account for the production of two goods.

Newspapers in period t, Q_t, are produced by n_t identical firms and the other good, X_t, is produced by m_t identical firms. The market prices for Q_t and X_t are $P_{Q,t}$ and $P_{X,t}$, respectively. Demands for Q_t and X_t are assumed to be a function of income and own price only; i.e., an increase in the price of Q_t does not alter the demand for X_t. All firms are assumed to behave competitively. Newspapers are produced using recycled old newspapers, $r_{Q,t}$, and virgin fiber, v_t, according to the production function $Q_t = f(r_{Q,t}, v_t)$. The subscript Q on $r_{Q,t}$ is used to distinguish old newspapers (ONP) used in the production of new newspapers from ONP used in the production of the other good, $r_{X,t}$.[8] The other good is produced from ONP and composite input, z_t, according to the production function $X_t = g(r_{X,t}, z_t)$. New producers of Q_t and X_t incur fixed costs, F_Q and F_X, respectively.

It is assumed that newspapers and other goods account for a sufficiently small share of the use of virgin fibers and the composite input that they do not affect prices; therefore, the prices of the virgin input, p_v, and the composite input, p_z, are exogenous and constant. In this simplified model, newspapers and other goods account for all of the old newspapers used and, therefore, affect prices. The marginal cost of supplying ONP (denoted $c_{r,t}$), therefore, is assumed to be a positive function of the total amount of ONP that is recycled, $n_t r_{Q,t} + m_t r_{X,t}$ (discussed below). The market for ONP is assumed to be competitive, so that the price of ONP, $p_{r,t}$, is equal to $c_{r,t}$. The total cost of supplying ONP is measured by the area under the supply curve.

Total disposal costs in t are a function of last period's production of newspapers and this period's choice of inputs. Specifically, the quantity disposed in period $t = n_{t-1}Q_{t-1} - n_t r_{Q,t} - m_t r_{X,t}$. Last period's production provides the potential total supply of waste while current recycling avoids disposal in the current period.

[7]This assumption is made for convenience but is not essential to the results.

[8]Note that there is only one market (and hence, one price) for ONP. The subscripts on r merely denote the ultimate ones of ONP.

The quantity of recycled newspapers used as inputs in the current period cannot exceed the quantity of newspapers produced in the previous period; i.e., $n_t r_{Q,t} + m_t r_{X,t} \leq Q_{t-1}$. A slack variable, s_t is used to transform this constraint into an equality. Specifically, $n_t r_{Q,t} + m_t r_{X,t} + s_t = Q_{t-1}$, where $s_t = Q_{t-1} - n_t r_{Q,t} - m_t r_{X,t}$ and $s_t \geq 0$.

Finally, administrative costs of the two policies are assumed to be zero. The implications of relaxing this assumption are discussed in Section VI of this paper.

The objective of the policymaker is to choose current production levels and input use in order to maximize social welfare. This necessitates taking into account the effect of both current input use on current disposal costs and current production on future disposal costs.

In order to maximize social welfare, it is necessary to maximize the difference between the total benefits that society receives from the consumption of the two goods and the costs that society bears due to the consumption of both goods (including disposal costs) subject to their production functions f and g. The total benefits associated with the production of Q_t and X_t are measured by the area under the market inverse demands for newspapers and the composite good, represented by $P_{Q,t}(\cdot)$ and $P_{X,t}(\cdot)$, respectively. The Lagrangian expression may be written as

$$\begin{aligned} L = {} & \int_0^{n_t Q_t} P_{Q,t}(s)\,ds + \int_0^{m_t X_t} P_{X,t}(h)\,dh - \int_0^{n_t r_{Q,t} + m_t r_{X,t}} c_{r,t}(k)\,dk - n_t p_t v_t \\ & - m_t p_z z_t - n_t F_Q - m_t F_X - d_t(n_{t-1} Q_{t-1} - n_t r_{Q,t} - m_t r_{X,t}) \\ & - d_{t+1}(n_t Q_t - n_{t+1} r_{Q,t+1} - m_{t+1} r_{x,t+1}) + n_t \delta_t(f(r_{Q,t}, v_t) - Q_t) \\ & + m_t \gamma_t(g(r_{X,t} z_t) - X_t) + \lambda_t(Q_{t-1} - n_t r_{Q,t} - m_t R_{X,t} - s_t), \\ & \qquad\qquad (\text{s.t. } s_t), \quad \text{s.t. } s_t \geq 0, \qquad (1) \end{aligned}$$

where

δ_t = the shadow price for the production of newspapers,

γ_t = the shadow price for the production of the composite good,

λ_t = the shadow price on the constraint that $n_t r_{Q,t} + m_t r_{X,t} \leq Q_{t-1}$.

Kuhn Tucker conditions for maximization indicate that $\lambda_t \geq 0$, $s_t \geq 0$, and $-\lambda_t s_t = 0$. Specifically, if this period's demand for recycled inputs is less than last period's production, then $s_t > 0$ and $\lambda_t = 0$. Conversly, if the demand for recycled newspapers exceeds last period's production, then $s_t = 0$ and $\lambda_t > 0$.

Currently 44% of all old newspapers are recycled [2]. As the recovery rate rises, the marginal cost of recovery increases for at least two reasons: old newspapers must be obtained from less accessible sources (e.g., rural communities and households opposed to recycling) and lower quality newspapers must be utilized (e.g., those contaminated by food, bleached by the sun, or exposed to moisture). Obviously, as the recovery rate approached 100%, the cost of obtaining usable additional newspapers would become prohibitive. Because it is assumed that the price of old newspapers is equal to the marginal cost of recovery (i.e., $p_{r,t} = c_{r,t}$), it is extremely unlikely that the demand for recycled newspapers could exceed the available supply. For simplicity, therefore, it is assumed throughout the rest of this analysis that $n_t r_{Q,t} + m_t r_{X,t} \leq Q_{t-1}$ is a non-binding constraint and that $\lambda_t = 0$.

First-order conditions may be used to obtain optimal levels of production of Q_t and X_t, selection of inputs, and number of firms. These first-order conditions are satisfied by a unique set of quantities, Q_t^*, X_t^*, $r_{Q,t}^*$, $r_{X,t}^*$, v_t^*, and z_t^*, and number of firms n_t^* and m_t^*. δ_t^* and γ_t^* are the shadow prices for the production of Q_t^* and X_t^*, respectively. $P_{Q,t}^*$, $P_{X,t}^*$, and $p_{r,t}^*$ are the market prices resulting from the optimal resource allocation. (Recall that p_v and p_z are exogenous and that $p_{r,t}$ is assumed to be equal to $c_{r,t}$.)

Optimal production levels, firm numbers, and resource use decisions may be expressed as

$$P_{Q,t}^* = \delta_t^* + d_{t+1} \tag{2}$$

$$P_{Q,t}^* \frac{\partial f}{\partial v_t}(v_t^*) = p_{v,t} + d_{t+1} \frac{\partial f}{\partial v_t}(v_t^*) \tag{3}$$

$$P_{Q,t}^* \frac{\partial f}{\partial r_{Q,t}}(r_{Q,t}^*) = p_{r,t}^* - d_t + d_{t+1} \frac{\partial f}{\partial r_{Q,t}}(r_{Q,t}^*) \tag{4}$$

$$P_{Q,t}^* Q_t^* = p_{r,t}^* r_{Q,t}^* + p_v v_t^* + F_Q + d_{t+1} Q_t^* - d_t r_{Q,t}^* \tag{5}$$

$$P_{X,t}^* = \gamma_t^* \tag{6}$$

$$P_{X,t}^* \frac{\partial g}{\partial z_t}(z_t^*) = p_z \tag{7}$$

$$P_{X,t}^* \frac{\partial g}{\partial r_{X,t}}(r_{X,t}^*) = p_{r,t}^* - d_t \tag{8}$$

$$P_{X,t}^* X_t^* = p_{r,t}^* r_{X,t}^* + p_z z_t^* + F_X - d_t r_{X,t}^*. \tag{9}$$

Equation (2) indicates that newspapers should be produced up to the point where their marginal value as indicated by the price, $P_{Q,t}^*$ is equal to their marginal cost to society. The marginal cost to society includes both the firm's private production costs, δ_t^*, and the future cost of disposing of the newspapers, d_{t+1}.

Likewise the use of inputs in the production of newspapers should reflect the total cost that society incurs from their use. Virgin materials should be used in the production of newspapers up to the point where the marginal revenue product is equal to the total factor cost, including both the price of the virgin material and the increase in disposal costs that its use in newspapers brings about (Eq. (3)). The total factor cost of ONP includes not only the future disposal costs associated with the newspapers that it produces but also the benefit of the current disposal costs that are avoided by the re-use of the ONP (Eq. (4)).

Equation (5) indicates that the optimal number of firms producing newspapers occurs when the profit from newsppaer production is zero, including the current disposal costs avoided by the use of ONP as a source of revenue and the future disposal of the newspapers themselves as a cost.

Equations (6)–(9) indicate the optimal level of production of the other good, X_t, optimal resource use in its production, and the optimal number of firms, m_t. Due to the additional benefit that society receives from the use of ONP in production, the optimal level of ONP used in X_t occurs when its marginal revenue product is equal to the price of ONP minus the current avoided disposal cost brought about by its use (Eq. (8)). Likewise the zero profit constraint (Eq. (9)) that determines the optimal level of firms, m_t, requires that the current avoided disposal costs be included as a source of revenue.

This section has illustrated the resource allocation that maximizes the social welfare of society. The following sections examine whether alternative policies can result in the optimal levels of production, number of firms, and use of inputs.

IV. RESOURCE USE UNDER A VIRGIN MATERIAL TAX

Is it possible to arrive at the optimal resource allocation under a virgin material tax? To explore this, the profit-maximizing decisions made by producers under a virgin material tax, T, are examined and compared to the optimal resource allocation. The Lagrangian expression for each newspaper producer is

$$L = P_{Q,t}Q_t - p_{r,t}r_{Q,t} - p_{v,t}v_t - Tv_t + \delta_t\big(f(r_{Q,t}, v_t) - Q_t\big). \tag{10}$$

The profit-maximizing quantities and their corresponding prices are denoted by a superscript T. Profit-maximizing production and input use levels may be written as

$$P_{Q,t}^T = \delta_t^T \tag{11}$$

$$P_{Q,t}^T \frac{\partial f}{\partial v_t}(v_t^T) = p_{v,t}^T + T \tag{12}$$

$$P_{Q,t}^T \frac{\partial f}{\partial r_{Q,t}}(r_{Q,t}^T) = p_{r,t}^T. \tag{13}$$

Firms will enter the industry up to the point where long-run profits are zero:

$$P_{Q,t}^T Q_t^T = p_{r,t}^T r_{Q,t}^T + p_v v_t^T + F_Q + Tv_t^T. \tag{14}$$

The Lagrangian for each producer of the other good is

$$L = P_{X,t}X_t - p_{r,t}r_{X,t} - p_z z_t + \gamma_t\big(g(r_{Q,t}z_t) - X_t\big). \tag{15}$$

Profit-maximizing production and input use levels may be written as

$$P_{X,t}^T = \gamma_t^T \tag{16}$$

$$P_{X,t}^T \frac{\partial g}{\partial z_t}(z_t^T) = p_z \tag{17}$$

$$P_{X,t}^T \frac{\partial g}{\partial r_{X,t}}(r_{X,t}^T) = p_{r,t}^T. \tag{18}$$

Firms will enter the industry up to the point where long-run profits are zero:

$$P_{X,t}^T X_t^T = p_{r,t}^T r_{X,t}^T + p_z z_t^T + F_X. \tag{19}$$

If the virgin material tax resulted in the socially optimal allocation of resources, the resulting firm production levels, input use levels, and the number of firms must be the same as those under the social optimum described above. That is, for the tax to result in the optimal resource allocation, the following relationships must hold: $Q_t^* = Q_t^T$, $X_t^* = X_t^T$, $v_t^* = v_t^T$, $r_{Q,t}^* = r_{Q,t}^T$, $r_X^* = r_{X,t}^T$, $z_t^* = z_t^T$, $n_t^* = n_t^T$, and $m_t^* = m_t^T$. Given that $Q_t^T = Q_t^*$, $P_{Q,t}^T$ must equal $P_{Q,t}^*$ since the tax on virgin materials does not shift the demand for newspapers; likewise, $P_{X,t}^T$ must equal $P_{X,t}^*$. The following discussion uses these equality constraints and examines what special conditions are necessary in order to make them hold.

Utilizing the constraint that $P_{Q,t}^T$ must equal $P_{Q,t}^*$ and comparing Eqs. (3) and (12) it is apparent that the tax will result in the optimal level of virgin material use in newspaper production only if the level of the tax is set so that $T = d_{t+1} \cdot \partial f/\partial v_t^*$; the tax must be set to reflect the marginal disposal cost associated with the optimal level of virgin material use in the production of newspapers.

Next, consider the conditions under which a tax on virgin materials will bring abut the optimal use of ONP in the production of newspapers; i.e., $r_{Q,t}^T = r_{Q,t}^*$. Again utilizing the constraint that the optimal resource allocation would cause $P_{Q,t}^T$ to equal $P_{Q,t}^*$ and comparing Eqs. (13) and (4) it is apparent that the marginal value product of ONP used in the product of newspapers will be equal under the tax and the social optimum only in the special case in which the marginal product of ONP in newspapers is equal to 1 and $d_t = d_{t+1}$.[9] In this case, current disposal costs avoided by re-using one ton of ONP are exactly offset by the future disposal costs brought about by the newspapers that are produced from one ton of ONP.

Available information indicates that $\partial f/\partial r_Q < 1$; therefore, the *quantity* of future disposal created by a marginal unit of ONP is less than the quantity of current disposal avoided by reusing one unit of ONP [4]. Whether the current disposal *costs* avoided the ONP used in production outweigh future disposal costs imposed by its marginal product depends on the growth in d over time. Given the short useful life of newspapers (i.e., this week's production is typically next week's garbage) it is reasonable to assume that d_{t+1} is equal to d_t and ONP used in newspapers production will decrease total (current plus future) disposal costs.

It should be noted, however, that $\partial f/\partial r_Q$ is less than one due to shrinkage of fibers and removal of inks in the water-intensive de-inking process. In this analysis it is implicitly assumed that these losses do not result in any adverse environmental effects. In reality, a full social optimum can be obtained only if all disposal options are priced correctly. Failure to properly price water discharges when instituting land disposal charges could result in a shift in disposal from one media to another. In order to maximize social welfare in this case it would be necessary to incorporate all environmental costs associated with the production of newspapers.

If the marginal product of ONP used in the production of newspapers is less than one, the optimal solution requires that the marginal value product of ONP used in newspapers reflect the net avoided disposal cost that the use of ONP brings about. In this case, a tax on virgin materials will not correctly subsidize the use of ONP. This is consistent with the findings of Stevens [12] that input charges will result in the optimal level of emissions only if inputs that reduce emissions are subsidized. Stevens also demonstrates that all inputs that contribute to emissions

[9] The above constraints require that $n_t^T = n_t^*$, $m_t^T = m_t^*$, $r_{Q,t}^T = r_{Q,t}^*$, and $r_{X,t}^T = r_{X,t}^*$. Since a competitive market is assumed, $p_{r,t} = c_{r,t}(n_t r_{Q,t} + m_t r_{X,t})$; therefore, $p_{r,t}^T$ must equal $p_{r,t}^*$.

must be taxed. An additional limitation of the virgin material tax that is not demonstrated in this simplified analysis is that it would not provide an efficient disincentive for the use of other inputs, such as capital and labor, even though they would have a positive effect on production and therefore, on disposal costs.

By comparing Eqs. (5) and (14) it can be seen that the zero profit condition under the tax will be equivalent to that under the social optimum only if

$$Tv_t^T = d_{t+1}Q_t^* - d_t r_{Q,t}^*. \tag{20}$$

If we assume that $d_{t+1} = d_t$ (as discussed above) then Eq. (20) may be written as

$$Tv_t^T = d_t(Q_t^* - r_{Q,t}^*). \tag{21}$$

Since we have already established that the marginal product of ONP used in the production of newspapers must be equal to one, the right-hand side of Eq. (21) may be written as $d_t \cdot v_t^* \cdot \partial f/\partial v_t^*$ provided that the margianl product of virgin materials is constant.[10] As discussed above, the level of the tax necessary to ensure that $v_t^T = v_t^*$ is $T = d_{t+1} \cdot \partial f/\partial v_t^*$, which is equal to $d_t \cdot \partial f/\partial v_t^*$ under the assumption that $d_t = d_{t+1}$. Therefore, under the conditions that $T = d_t \cdot \partial f/\partial v_t^*$, $\partial f/\partial r_Q = 1$, and the marginal product of virgin materials is constant, the zero profit condition under the tax will be equivalent to that under the social optimum and $n_t^T = n_t^*$. If the marginal product of virgin materials is decreasing then $d_t(Q_t^* - r_{Q,t}^*) > d_t \cdot v_t^* \cdot \partial f/\partial v_t^*$. In this case, a tax set equal to $d_t \cdot \partial f/\partial v_t^*$ will result in too many firms in the industry.

Carlton and Loury [10] examine the case in which the amount of pollution damage is a function of both the scale of the firm (Q, in this case) and the number of firms. They demonstrate that an output tax must be linked with a lump sum tax or subsidy, depending on whether marginal damages are falling or rising at the optimal scale in order to achieve the social optimum.

In the situation examined above, the damage (i.e., disposal cost) per unit of output is constant, but the damage per unit of virgin input is falling if virgin materials have a declining marginal product. In this case, a virgin material tax would not sufficiently discourage entry into the industry. An additional lump sum tax would be necessary to result in the correct number of firms. The level of this tax should be equal to the difference between the amount of disposal costs resulting from each firm's production, $d_{t+1}Q_t^* - d_t r_{Q,t}^*$, and the firm's tax payments, Tv_t^T.

Spulber [10] correctly points out that the Carlton and Loury finding that both an output and a lump sum tax are necessary to achieve optimal control occurs because in their example a tax on output is not equivalent to a direct tax on damages. In the disposal problem examined here, an output tax is an appropriate policy tool because the damage (i.e., future disposal costs) is linked to the output itself and is not a function of the combination of inputs used. As pointed out in the following section, the fact that the use of old newspapers as an input in production results in avoided current disposal costs necessitates that an output tax be combined with a reuse subsidy.

[10]Note that this result is based on Euler's theorem.

Finally, we can compare resource use in the composite other good under a virgin material tax and under the social optimum. As described above, optimal resource allocation requires that $P^T_{X,t} = P^*_{X,t}$ and $p^T_{r,t} = p^*_{r,t}$. Given that $p^T_{r,t} = p^*_{r,t}$, however, it is obvious from comparing Eqs. (8) and (18) that the marginal value product of ONP used in the composite good *cannot* be equivalent under the tax and the social optimum provided that $d_t > 0$. If use of ONP in the production of the other good results in positive avoided disposal costs, then these benefits must be accounted for in the input use decision. A tax on virgin materials, however, does not provide any incentive to increase the use of ONP in products where it does not displace virgin materials, such as exports or animal bedding. This may be the greatest limitation of the virgin material tax.

Ideally, all possible uses of ONP would receive equal encouragement for expansion in order to avoid current disposal expenses at the lowest possible cost to society. By encouraging some uses, but not others, a virgin material tax does not provide appropriate incentives for an efficient expansion of recycling (i.e., the marginal cost of additional recycling will not be equal across all end uses). Exports, which are not encouraged by a virgin material tax, are a large and growing use of ONP. (Exports accounted for over 19% of ONP recovered in 1991 [13].) In addition, depending on how all-encompassing the definition of "virgin material" is that is subject to the tax, other end uses may also avoid disposal costs while not replacing virgin materials. For example, old newspapers may be made into animal bedding (replacing straw). This end use would not replace virgin materials under most conventional definitions and would not, therefore, be encouraged by a virgin material tax even though it resulted in avoided disposal costs.

V. RESOURCE USE UNDER A COMBINATION DISPOSAL TAX AND REUSE SUBSIDY

Is it possible to arrive at the optimal resource allocation with a combination disposal tax and reuse subsidy? To explore this, we can examine the production decisions made by profit-maximizing firms under a disposal tax, T_d, and a reuse subsidy, s. The Lagrangian for newspaper producers is

$$L = P_{Q,t}Q_t - T_d Q_t - p_{r,t} r_{Q,t} + s r_{Q,t} - p_{v,t} v_t + \delta_t\big(f(r_{Q,t}, v_t) - Q_t\big). \tag{22}$$

The profit-maximizing quantities and their corresponding prices are denoted by a superscript c. Profit-maximizing production and input use levels may be written as

$$P^c_{Q,t} = \delta^c_t + T_d \tag{23}$$

$$P^c_{Q,t} \frac{\partial f}{\partial v_t}(v^c_t) = p_{v,t} + T_d \frac{\partial f}{\partial v_t}(v^c_t) \tag{24}$$

$$P^c_{Q,t} \frac{\partial f}{\partial r_{Q,t}}(r^c_{Q,t}) = p^c_{r,t} - s + T_d \frac{\partial f}{\partial r_{Q,t}}(r^c_{Q,t}). \tag{25}$$

Firms will enter the newspaper industry up to the point where long-run profits are zero:

$$P^c_{Q,t} Q^c_t = p^c_{r,t} r^c_{Q,t} + p_v v^c_t + F_Q + T_d Q^c_t - s r^c_{Q,t}. \tag{26}$$

The Lagrangian for producers of the other good is

$$L = P_{X,t}X_t - p_{r,t}r_{X,t} + sr_{X,t} - p_z z_t + \gamma_t\big(g(r_{Q,t}, z_t) - X_t\big). \tag{27}$$

Profit-maximizing production and input use levels may be written as

$$P^c_{X,t} = \gamma^c_t \tag{28}$$

$$P^c_{X,t}\frac{\partial g}{\partial z_t}(z^c_t) = p_z \tag{29}$$

$$P^c_{X,t}\frac{\partial g}{\partial r_{X,t}}(r^c_{X,t}) = p^c_{r,t} - s. \tag{30}$$

Firms will enter the industry up to the point where long-run profits are zero:

$$P^c_{X,t}X^c_t = p^c_{r,t}r^c_{X,t} + p_z z^c_t + F_X - sr^c_{X,t}. \tag{31}$$

If the combined disposal tax and reuse subsidy result in the optimal resource allocation then the following relationships must hold: $Q^*_t = Q^c_t$, $X^*_t = X^c_t$, $v^*_t = v^c_t$, $r^*_{Q,t} = r^c_{Q,t}$, $r^*_{X,t} = r^c_{X,t}$, $z^*_t = z^c_t$, $n^*_t = n^c_t$, and $m^*_t = m^c_t$. As in the case of the virgin material tax, the quantity equivalency constraints imply that $P^c_{Q,t} = P^*_{Q,t}$, $P^c_{X,t} = P^*_{X,t}$, and $p^c_{r,t} = p^*_{r,t}$. By using these constraints and comparing Eqs. (23)–(26) with Eqs. (2)–(5) and Eqs. (28)–(31) with Eqs. (6)–(9), it can easily be seen that the disposal tax/reuse subsidy policy will result in the optimal resource allocation provided that $T_d = d_{t+1}$ and $s = d$. In this case, the private costs of production that firms face will be consistent with the social costs of production and profit-maximizing decisions will be expected to result in optimal production levels, input use, and number of firms.[11] This result is similar to that of Holterman [5]. She demonstrates that a tax on output and a subsidy on inputs can result in an efficient solution when it is not possible to directly tax an externality. In her analysis one firm's output reduces other firm's profits and some inputs are a substitute for output of the externality.[12]

[11] If some disposal costs are already accounted for in decisions about recycling, then a share of the avoided disposal costs are reflected in ONP prices and the subsidy should be adjusted to cover only the share of disposal costs that are not accounted for.

[12] In addition to the efficiency implications of the two policies, their distributional consequences may be of interest since this will influence the extent to which they are supported by affected industries. A disposal tax/reuse subsidy policy results in disposal fee being imposed only on products that are ultimately disposed and is, therefore, analogous to an emissions fee (i.e., waste is emitted to landfills). Stevens [12] demonstrates that industry will be indifferent to input charges or emissions fees if there are constant returns to scale in production of emissions and will prefer an emissions tax if there are increasing returns to scale. Because the assumptions necessary to obtain an efficient level of waste disposal with a virgin material tax include both closed-loop recycling and constant returns to scale, these assumptions would also imply that industry would be indifferent between a virgin material tax and a combined disposal tax and reuse subsidy. Under the more realistic assumption that all recycled newspapers are not used in producing new newspapers (regardless of whether there are constant returns to scale in production), the two policies will not generate the same amount of waste or result in the same amount of revenue. In this case, industries will not be indifferent between the two. For example, in the context of this model, producers of X will benefit under the tax/subsidy policy but not under the virgin material tax. In addition, the tax/subsidy policy will be preferred by newspapers producers if there are increasing returns to scale in the production of newspapers (and, therefore, disposal requirements) from virgin inputs.

VI. ADMINISTERING A COMBINED DISPOSAL TAX AND REUSE SUBSIDY

While a combined disposal tax and reuse subsidy is theoretically capable of maximizing social welfare, this analysis has not considered the cost of administering such a policy. A full benefit–cost analysis is necessary to weigh the welfare gains from incorporating disposal costs into production and recycling decisions against the cost of administering the policy. (For a more complete discussion of administrative issues, see [15].)

Administering the policy would involve collecting the disposal tax from all producers and importers of the covered product and providing the subsidy to all end users of the recovered material.[13] It would obviously be prohibitively expensive to administer such a policy for the wide range of consumer products that are disposed of. This policy would need to be limited to items that compose a particularly large share of the waste stream (such as newspapers) or that have particularly high per unit disposal costs (discussed further in the following section).

Administrative costs of the disposal tax are likely to be lower when there are a limited number of producers and importers of the product and when the product is easily identified. For example, a disposal tax on "glass" would be difficult to administer since customs officials would have to identify the glass component of a wide variety of products, including items such as the glass component of imported cars. Narrowing the policy to cover a limited number of readily identifiable items, such as glass beverage containers, would simplify matters.

The reuse subsidy would be relatively easy to administer if only a small number of firms were eligible for the subsidy. Limiting eligibility to firms that use more than a minimum amount of the covered materials may be one way to eliminate many small end users, while ensuring that the bulk of the recovered material receive the benefit of the subsidy.

Choosing the unit that the tax and subsidy are based on may involve a compromise between accurately reflecting disposal costs and administrative ease. Some solid waste disposal costs depend on the volume of a good while others depend on weight and material type [14]. To facilitate implementation, however, fees based on weight or well-defined units (e.g., per bottle) would be necessary.

VII. COMPARISON OF A COMBINED DISPOSAL TAX AND REUSE SUBSIDY WITH UNIT-BASED PRICING

As described in Section I of this article, the fundamental inefficiency associated with waste disposal is flat-fee pricing. An obvious solution, therefore, is to levy household disposal costs that are based on the amount of waste that the household generates. This solution has actually been implemented in several communities [7]. This article has shown that a combined disposal tax and reuse subsidy policy could also provide signals for an efficient level of waste generation.

[13]Alternatively, the disposal tax could be levied at the final point of sale of the product, rather than at the point of production. This would involve collecting the tax from numerous retailers and distributors and would be likely to result in higher administrative costs unless the collection system could build on existing sales tax collection systems [17].

Under both systems, goods that are produced and then recycled avoid disposal cost charges (under the tax/subsidy policy the initial tax is canceled out by the subsequent subsidy).[14] Similarly, a good that is produced but not recycled incurs a disposal charge under both systems.

Although these approaches are theoretically the same in the charges that they impose on products, there are important differences between them that can make one preferable over the other depending on the characteristics of the good. First, under unit-based pricing, households are typically charged the same for each unit of trash (can, bag, or pound) regardless of the contents. Not all types of trash impose the same disposal costs, however. For example, a bag full of old tires or old batteries is more costly to dispose of than a bag full of papers. (Tires tend to "float" in landfills and, therefore, must be shredded; batteries pose a greater potential environmental threat than paper.)[15] A tax/reuse subsidy policy may be better suited to deal with potentially recyclable waste items that have higher than average disposal costs.

A particular concern associated with unit-based pricing is that it provides households with an economic incentive to engage in illegal disposal (e.g., burning waste, dumping it in vacant lots or in private dumpsters) (see [9, 7]). A disposal tax/reuse subsidy policy may be preferable to unit-based pricing in communities that are thought likely to have high levels of illegal disposal or for goods that pose particularly high environmental costs when disposed of improperly (e.g., used oil).

In addition, the placement of the disposal charge, either on the product and input under a tax/subsidy policy or on the household with unit-based pricing, may affect the relative awareness of households and producers to the charge, and therefore their response. How awareness and responses might vary with the placement of the charge is an empirical question that is unanswered at this point.

Finally, the administrative costs of the two policies may differ significantly. A national unit-based pricing program would require all public and private waste collectors to change their operating systems. Variable can charges involve far more record keeping and monitoring than flat-fee pricing. Pay-by-the-bag systems involve extensive distribution of bags as well as increased monitoring (see [14, pp. 7–8]). In addition, further enforcement would be necessary to prevent illegal disposal. A tax/subsidy policy would also have high administrative costs. It would be prohibitively expensive to implement this policy to all items in the waste stream. This policy would be best targeted at selected items in the waste stream. Candidate items would include those that compose a relatively large share of municipal solid waste, such as ONP or old corrugated cardboard containers, and items that are particularly difficult or environmentally harmful to dispose of, such as lead acid batteries and old tires.

VIII. CONCLUSIONS

There are several problems associated with using a virgin material tax to achieve optimal resource use. The most obvious, and perhaps the most significant, is that a virgin material tax will not encourage the use of ONP in goods that do not displace

[14]This is based on the assumption that $d_t = d_{t+1}$, which is likely to be the case for most short-lived, commonly recycled items, such as containers and newspapers.

[15]See [17] for further discussion of this.

virgin materials (e.g., exports or animal bedding). If there are avoided disposal costs associated with the use of ONP in these other goods (as there is in the case of exports) then the virgin material tax will result in an underallocation of ONP in the production of these goods.

The second limitation of a virgin material tax is that, although it can be set to reflect the marginal disposal costs associated with the use of the virgin material in the production of newspapers, it cannot reflect the *net decrease* in disposal costs that ONP used in newspaper production brings about. These net avoided disposal costs are positive if the marginal product of ONP in newspaper production is less than 1 (provided that $d_{t+1} = d_t$, a reasonable assumption for short-lived products such as newsprint). This finding should be caveated by the fact that losses in the production of recycled newsprint (creating a marginal product of less than 1) may not be environmentally benign or priced appropriately. Environmental damages to other media (e.g., water) could lessen the advantage of recycled newsprint production. Future work might attempt to model the effects of recycled and virgin newsprint production on all media.

Finally, even given the special set of restrictions described above, a virgin material tax could result in the optimal number of firms in the newspaper industry only if the marginal product of virgin materials used in the production of newspapers was constant.

A combined disposal tax/reuse subsidy policy would result in the socially optimal resource allocation provided that the tax was set equal to the future disposal cost, d_{t+1}, and the subsidy was set equal to the cost of current disposal. This policy would cause producers to take future disposal costs into account in their production decisions and would cause them to consider avoiding current disposal costs when choosing between materials that are recovered from the waste stream (such as ONP) and other inputs.

A combined disposal tax and reuse subsidy policy is theoretically consistent with the incentives provided by unit-based pricing. The disposal tax/reuse subsidy policy, however, has some advantages in that it does not provide an incentive for illegal disposal and the taxes and subsidies can vary across products to reflect differences in disposal costs. A limitation of the tax/subsidy policy is that it could be implemented for only selected items in the waste stream.

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