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Upstream Pollution, Downstream Waste Disposal and the Design of Comprehensive Environmental Policies

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Abstract

In this paper, we expand our earlier model of production, consumption, and solid waste disposal (Palmer and Walls, 1997) to include upstream pollution problems such as manufacturing effluent and greenhouse gas emissions from energy use in production. We derive a set of taxes and subsidies that can be used to achieve the socially optimal levels of both upstream pollution and downstream waste disposal when Pigouvian taxes are infeasible. Some observers have suggested use of a single instrument to address "life-cycle" pollution concerns, one example being an "advance disposal fee (ADF)" – i.e., a final product tax that reflects the full environmental costs of the product. We find that no *single* tax or subsidy can generate the optimum. However, taxes on output can be combined with taxes on and subsidies to raw material inputs to achieve the same outcome as Pigouvian taxes. We also find that the optimal policy to address waste disposal concerns – a deposit-refund – is lower when accounting for upstream pollution. When we incorporate existing upstream pollution standards expressed as limits per unit of output, we find that such standards must be combined with output taxes to generate the optimum. When the upstream pollutant of concern is greenhouse gas emissions associated with energy use in production, we find that the specification of optimal alternative taxes and subsidies depends on the form of each firm's production function, and, therefore, these policies may be very difficult to implement in practice.

Key words: life-cycle pollution, solid waste, deposit-refund, virgin materials tax

JEL classification code: Q28

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I. Introduction

In recent years, environmentalists and environmental policy makers have focused increasing attention on the so-called "life-cycle" environmental problems associated with consumer products. Concern over the disposal of solid waste generated from such products grew, in many quarters, to encompass other "upstream" environmental problems. This led to a rash of Product Life-Cycle Assessments (PLCAs) -- enumerations of all of the resources used and pollutants emitted throughout the life-cycle of a product, from resource extraction through product disposal. The most notable of these studies were the comparisons of cloth to disposable diapers and polystyrene to paper cups (Franklin Associates, Ltd., 1990; Hocking, 1991). Although the methodology has its critics (Arnold, 1993; Menell, 1995; Morris and Scarlett, 1996; and Portney, 1993/94), advocates of PLCAs claim a myriad of uses for them, from a basis for eco-labeling to a means of establishing environmental product taxes (Ackerman, 1993).[2]

Concern about life-cycle externalities is part of a broader focus on multi-media pollution in general. Many experts have long criticized the fragmented, media-specific nature

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[1] We appreciate the helpful comments of Don Fullerton, Paul Portney, and Hilary Sigman.

[2] Some local and state governments in the United States are using the results of PLCAs to assist them in procuring "environmentally-friendly" products (Center for Study of Responsive Law's Government Purchasing Project, 1996). Standards for life-cycle assessments are one of the six categories in the ISO 14000 international environmental management standards (Tibor and Feldman, 1996). See Gloria et al. (1995) for a survey of private companies using the approach and Kuta et al. (1995) for three case studies. So called "stream-lined life cycle inventories" have become key in efforts to assess greenhouse gas emissions associated with all stages of a product life-cycle (U.S. EPA, 1997).

of U.S. environmental laws, arguing that they can lead to spillover effects into other media and excessive pollution control costs (see Guruswamy, 1991, and U.S. General Accounting Office, 1996). Several countries -- Great Britain, Sweden, the Netherlands, Japan, and New Zealand, for example -- have more broad-based, multi-media laws on the books.[3] The U.S. Environmental Protection Agency has addressed this concern in part by developing voluntary programs for industry, such as the Common Sense Initiative and the 33/50 Program, which encourage integrated management of the environmental impacts associated with production and the use of source reduction -- the downsizing of products or packaging, reduction of raw material use, and/or reduction in the use of toxic substances -- as more sensible means of reducing pollution than end-of-pipe treatments.[4]

Increased attention to life-cycle and multi-media pollution issues has led to other proposals to expand the scope of traditional environmental regulations, including regulations originally designed to reduce solid waste, to address multiple pollution concerns. For example, some observers have suggested that a single tool such as a deposit-refund or an "advance disposal fee" -- a product tax which may be partially refunded if a product is recycled -- be used to correct for life-cycle externalities (Ackerman, 1993). Environmental policymakers also have been considering how to design policies that address greenhouse gas emissions in conjunction with other environmental problems, including waste disposal. The idea is that different policies designed to reduce disposal will also yield different amounts of ancillary greenhouse gas reductions; these effects should be taken into account, some argue, when choosing among policies (U.S. EPA, 1997).

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[3] See Hersh (1996) and Haigh and Irwin (1990) for assessments of the experiences in some of these countries.

[4] See Davies and Mazurek (1996) for an evaluation and critique of these programs and discussion of source reduction over "end-of-pipe" controls.

In this paper, we extend our earlier theoretical model of optimal solid waste disposal (Palmer and Walls, 1997) to address environmental externalities that occur throughout the life-cycle of a consumer product. We focus on a world in which Pigouvian taxes on these externalities are infeasible. First, we use the model to derive optimal government policies for addressing both an upstream problem such as effluent from a manufacturing process discharged into a waterway and downstream solid waste disposal. Second, to address some of the arguments made by critics of PLCAs, we incorporate existing effluent regulations into the model to see whether, in the presence of such regulations, there is any need for further government intervention upstream. Finally, we alter the model to include energy as an additional input into production. This allows us to consider the design of policies to address both greenhouse gas emissions and downstream waste disposal.

In the view of economists, the basic Pigouvian prescription for addressing environmental externalities through emission taxes is not necessarily altered by the existence of multi-media, or life-cycle, externalities. However, in a world where Pigouvian taxes are infeasible, the problem of how to address multi-media pollution becomes more challenging. Several economists have examined alternatives to Pigouvian taxes for a single media problem. For example, it is well-recognized that direct charges for solid and hazardous waste disposal are likely to be impractical because of the potential for illegal disposal (see Dinan, 1993; Fullerton and Kinnaman, 1995; Sigman, 1995; Palmer and Walls, 1997; Palmer, Sigman, and Walls, 1997). Other authors have argued that when monitoring and enforcement problems are large, solutions other than Pigouvian taxes might be necessary -- either other incentive-based approaches or some type of command-and-control approach. These authors address problems ranging from automobile emissions (Innes, 1996; Eskeland, 1994) to emissions from dry cleaners (Macauley, Bowes, and Palmer, 1992). Eskeland and Devarajan (1996) and Fullerton and Wolverton (1997) present general discussions of alternative taxes and combinations of tax instruments and standards. None of these studies addresses multi-media or life-cycle pollution concerns.

In this paper, we find that multiple policy instruments are necessary to fully address both an upstream externality and downstream disposal. If the upstream externality cannot be addressed through a direct, Pigouvian-type tax, then the optimal policy set always includes a tax on virgin material inputs to production. To generate the optimal amount of solid waste disposal as well, the virgin materials tax must be coupled with a deposit-refund -- i.e., a tax on the final product and a subsidy to recycling. The deposit-refund result is consistent with previous findings in the literature, but the optimal deposit-refund is lower when the upstream pollution problem is taken into account. These results lend some merit to the notion of encouraging source reduction as advocated by many observers and encouraged by the Common Sense Initiative and the 33/50 Program. The tax on virgin materials reduces the raw material input used in production – i.e., promotes source reduction – and this, in turn, lowers the deposit-refund necessary to achieve the optimal amount of solid waste disposal. Thus, as some have argued, encouraging source reduction does lower the cost of achieving the downstream environmental goal.

When we allow for existing effluent regulations, there may still be a need for a virgin materials tax, depending on the type and stringency of the regulations. Most water pollution regulations and some air pollution regulations applied to industrial sources limit effluent *per unit of output produced.* In this case, there is always a need for an output tax to generate the social optimum. However, it may be possible to set the standard and the output tax in such a way that a virgin materials tax is unnecessary. The fact that the standard is set on a *per unit of output* basis leads to the need for a tax on output to discourage over-production. The deposit-refund is still necessary to address downstream disposal.

When we include energy as an input to production, with its concomitant greenhouse gas emissions, a tax on output and a subsidy to all non-energy inputs will achieve the same result as a

Pigouvian tax on energy. Fullerton and Wolverton (1997) reach an identical result – which they call a "two-part instrument" -- in a model without life-cycle externalities.

Our focus in this paper is limited to the issue of pollution across the different stages of a product's life-cycle in a world in which Pigouvian taxes are infeasible and to evaluating some of the claims made by policymakers and environmentalists about the life-cycle effects of different policies. We do not address many other important multi-media pollution concerns. For example, we do not consider the problem of multiple upstream pollutants. Empirical work by Sigman (1996), using data from the U.S. Toxics Release Inventory, shows interesting cross-media effects of upstream regulations on chlorinated solvent waste disposal and air emissions. Moreover, we do not specifically address the issue of substitution of non-toxic for toxic substances, nor the possibility of emissions into one media (say, air) leading to pollution in another media (say, water).[5] These are important multi-media issues deserving of economists' attention but beyond the scope of the current paper.

The combinations of taxes and subsidies we derive in each of our scenarios are theoretically equivalent to Pigouvian taxes – i.e., they achieve a first-best allocation of resources. Whether they would be preferred *in practice* to Pigouvian taxes, however, depends on the extent to which Pigouvian taxes are infeasible and the extent to which the taxes and subsidies proposed here *are* feasible. This is an important question, the answer to which will vary depending on the industry and pollutant under consideration. We present a brief discussion below.

In the following section, we present the model and the social optimum. In section III, we assume that neither downstream waste disposal nor upstream manufacturing effluent are priced at their marginal social cost and solve for the set of taxes that will generate the social optimum. We do this both without and with existing command-and-control style regulations on the upstream

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[5] For a study along these lines, see Austin, Krupnick, and McConnell (1997) for a discussion of the effects of airborne nitrogen oxide emissions on pollution in the Chesapeake Bay.

effluent. In section IV, we add energy as an input to the model, with a concomitant externality, and solve for the set of alternative taxes to generate the social optimum. Section V discusses the feasibility issues associated with Pigouvian taxes and our alternative policies. The final section of the paper offers some concluding remarks.

II. The Model and the Social Optimum

The model is described fully in Palmer and Walls (1997). On the production side, we assume that there are n identical perfectly-competitive firms in the consumer product industry, each of which uses virgin materials, v, and recycled materials, r, to produce output, q; each also uses an additional, nonmaterial input which we will call labor, l (in section III below, we will add an energy input, e). The firm's production function is given by $q = f(v, r, l)$.

We assume that there is a residual associated with the production process that is a function of the amount of inputs used and it is denoted $z = z(v, r, l)$. This production residual could take a number of different forms ranging from particles emitted into the air at aluminum smelters to BOD effluent released into waterways by paper manufacturing. In our derivation of the social optimum, we assume that the firm pays a price, p_z, to dispose of the production residual and this price reflects the full marginal social costs of the residual. The firm takes all prices -- the price of output, P_q, the price of the virgin material, p_v, the price of recyclables, p_r, the price of labor, p_l, and the charge for disposing of its own residual, p_z, as given.

The consumer side of the market is represented by the (inverse) market demand function, $P_q(nq)$. Consumers also make decisions about recycling and disposal of used products. We assume that each consumer has increasing marginal costs of recycling and that this leads to a market supply curve for recyclables represented by $c_r(nr)$. Consumers take the price of solid waste disposal, p_d, as given. In the derivation of the social optimum, this price is assumed to reflect the full marginal social cost of disposal of municipal solid waste, including all environmental costs.

We assume that a mass balance condition must hold -- i.e., that the sum of all new material inputs used in the production process across all firms must equal the sum of all residuals from consumption and production or $nv = D + nz$, where D is the total quantity of solid waste disposal. Total disposal equals total production minus total recycling or $D = n(q - r)$.[6] Substituting this expression for D into the materials balance condition yields $nv+nr = nq+nz$, or $v+r = q+z$.

The socially optimal levels of v, r, l, and D are determined by maximizing net social surplus subject to the materials balance condition. Substituting for D and incorporating the constraint by substituting for z yields the following objective function:

$$(1) NSS = \int_0^{nf(v,r,l)} P_q(s)\,ds - \int_0^{nr} c_r(x)dx - np_v v - np_l l - np_z(v + r - f(v,r,l)) - np_d(f(v,r,l) - r)$$

Maximizing NSS with respect to v, r, and l under the assumption that the market for the secondary material is in equilibrium, and therefore $p_r^* = c_r$, yields the following first-order conditions:

$$(2) \left(P_q^* + p_z - p_d\right)\left(\frac{\partial f}{\partial v}\right) = p_v + p_z$$

$$(3) \left(P_q^* + p_z - p_d\right)\left(\frac{\partial f}{\partial r}\right) = p_r^* + p_z - p_d$$

$$(4) \left(P_q^* + p_z - p_d\right)\left(\frac{\partial f}{\partial l}\right) = p_l$$

where P_q^* is the market-clearing price of output.

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[6] To avoid issues of discounting and price changes over time, we assume that products last only one period or that the market is in a long-run steady state.

According to these three first-order conditions, each input should be employed until the social value of its marginal product, given by the expression on the left-hand side of each equation, is equal to its net price. The social value of each input's marginal product is the marginal product multiplied by the value of the additional output produced; the value of the additional output is the price of the output plus the avoided marginal social cost of the manufacturing effluent (since the more output obtained from the inputs, the less residual effluent produced) less the additional solid waste disposal cost from the additional output. The net price of the virgin input equals the sum of the market price of virgin materials and the marginal social cost of the manufacturing effluent. The net price of the secondary material equals its market price less the marginal disposal cost avoided plus the marginal social cost of the manufacturing effluent.

In Palmer and Walls (1997; 1994), we show that if the manufacturing effluent is priced at its marginal social cost but solid waste disposal is free, then the optimal policy is a deposit-refund equal to the marginal social cost of disposal, p_d. We also show that either a virgin materials tax or a recycled content standard – a requirement that a certain fraction of total material input be comprised of secondary materials – can achieve the optimum only if combined with an output tax and a labor tax. Moreover, the form of these policies is quite complicated and would be difficult to implement in practice. The deposit-refund would usually be the preferred option.[7]

In the next section, we derive the optimal set of policies when both solid waste disposal and disposal of the manufacturing effluent is free; in the ensuing section, we allow for existing, command-and-control style regulation of the manufacturing effluent.

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[7] In a similar model, Dinan (1993) also highlights the problems with a virgin materials tax.

III. Optimal Policies to Address Upstream Pollution and Downstream Waste Disposal

A. *The Case of an Unregulated Upstream Pollutant.* In this first section, we assume that the manufacturing effluent is disposed of for free, as is solid waste, and there are no regulations governing the effluent. In a private market, a perfectly competitive firm chooses its inputs to maximize profits, taking all prices as given:

$$(5)\,\Pi = (P_q - t_q) f(v,r,l) - (p_r + t_r)r - (p_v + t_v)v - (p_l + t_l)l$$

where t_q is the tax on output, t_r the tax on the secondary material input, t_l the tax on labor, and t_v the tax on virgin materials. The first-order conditions are:

$$(6)(P_q - t_q)\left(\frac{\partial f}{\partial v}\right) = p_v + t_v$$

$$(7)(P_q - t_q)\left(\frac{\partial f}{\partial r}\right) = p_r + t_r$$

$$(8)\,(P_q - t_q)\left(\frac{\partial f}{\partial l}\right) = p_l + t_l$$

Assuming $P_q = P_q^*$ and $p_r = p_r^*$ (conditions that must hold to achieve the optimum) and comparing equations (6), (7), and (8) to the socially optimal first-order conditions (2), (3), and (4), we note that the expressions are identical as long as the following conditions hold:

$$\begin{array}{ll} t_q = p_d - p_z & \quad t_v = p_z \\ t_r = p_z - p_d & \quad t_l = 0 \end{array}$$

We find, then, that a deposit-refund –i.e., a combined product tax and recycling subsidy -- is still optimal but it has a slightly different form than in the case where only waste disposal was a concern. The tax on output and the subsidy to recycling are now both reduced by the amount p_z. In fact, if p_z is larger than p_d – i.e., the marginal social cost of the manufacturing effluent is greater than the marginal social cost of waste disposal – the optimal policy could be an output subsidy and a recycling tax. The optimal policy set now also includes a virgin materials tax equal to the marginal social cost of the manufacturing effluent.

The form of the materials balance condition generates these new results. The materials balance condition states that all new material inputs must ultimately be converted into some type of waste: $nv=nz+D$. If we need to tax z but cannot, an equivalent policy is a tax on v and a subsidy to D; since disposal is simply consumption less recycling ($D=nq-nr$), the subsidy to disposal is equivalent to a subsidy to output and a tax on recycling. We also need to tax disposal but cannot, thus an equivalent policy is a tax on output and a subsidy to recycling (as in our earlier paper). Combining these alternative taxes and subsidies to address the two externalities gives the results above.

These results are roughly consistent with the notion of promoting source reduction as a sensible means of reducing pollution. The virgin materials tax here reduces virgin materials use – i.e., encourages source reduction – and also reduces the size of the optimal deposit/refund – i.e., *lowers* the cost of achieving the optimal amount of downstream waste disposal. In other words, source reduction helps to solve the downstream pollution problem. These results make sense given the mass balance requirement. Taxing virgin materials to reduce the upstream pollutant reduces the amount of output produced and waste generated, thus the optimal deposit/refund is lower.

There is an important footnote to the above results. The assumption that disposal itself cannot be taxed is based, primarily, on the idea that such a tax would lead to an unacceptable amount of illegal dumping. It might be possible to *subsidize* disposal, however. If so, then an equivalent set of taxes to those outlined above would be:

$$t_d = -p_z \qquad t_v = p_z$$
$$t_q = p_d \qquad t_l = 0$$
$$t_r = -p_d$$

The optimal deposit-refund is now identical to that derived when only the waste disposal externality was a concern. And again, the inability to tax z, and the form of the mass balance identity leads to the necessary tax on virgin materials and *subsidy to proper disposal*, both equal to p_z.

B. *The Case of Effluent Regulations.* Most industrial pollution in the U.S. and other OECD countries is subject to command-and-control style regulation. Menell (1995) and Portney (1993/94), in their assessments of the PLCA methodology, argue that this existing regulation should result in significant internalization of production externalities. They argue that PLCAs can present a misleading picture of the magnitude of environmental problems as a result. We address these issues more formally here.

Industrial air and water pollution regulations take various forms. Water effluents such as BOD (biochemical oxygen demand) or TSS (total suspended solids) are subject to limits per unit of output produced. Pulp and paper manufacturers – often the target of solid waste disposal and recycling initiatives and the single largest emitter of BOD in the U.S. as well as a significant source of TSS – face limits per ton of paper produced per day.[8] Battery manufacturers, primary metal producers, and iron and steel producers, among others, face limits on TSS and a number of chemicals and hazardous substances, all expressed on a per unit of output produced basis.

Air emissions regulations in the U.S. are more of a mixed bag. Much of the air pollution from industrial sources comes from burning fuel and regulations governing

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[8] Permits for BOD and TSS are actually issued to a facility on a pounds per day basis assuming that the facility operates at full capacity. This means that the standard actually varies to some degree with the amount of output produced rather than being a fixed limit over all units. We ignore this detail in our model here.

emissions from these processes are usually stated as pounds of pollutant per unit of heat input. However, when air emissions are more directly related to the industrial process they may be stated in terms of pollutant per unit of output. For example, the new source performance standard (NSPS) for particulate emissions from glass manufacturing is stated in terms of pounds of particulates per pound of glass produced. Other NSPSs are written as a limit per unit of raw material input. Still others are written as parts per million of total gas emissions. In general, the form of U.S. air pollution standards, either for new sources or for existing sources, varies considerably by industry and by pollutant. It is impossible for us to analyze all the different types of regulations here. Because some air pollution standards and most water pollution standards are expressed as a per unit of output, we focus on this type of standard.

Specifically, we assume that the effluent in our model, z, is subject to a limit per unit of output, q, and we represent this as: $z / q \leq \Omega$ or $z \leq \Omega f(v, r, l)$. Assuming the constraint is binding and substituting $v+r-f(v,r,l)$ for z, as before, yields the following constrained optimization problem for the firm:

$$(9)\ L = (P_q - t_q) f(v,r,l,) - (p_r + t_r) r - (p_v + t_v) v - (p_l + t_l) l + \lambda\left(v + r - f(v,r,l) - \Omega f(v,r,l)\right)$$

The first-order conditions are:

$$(10)(P_q - t_q - \lambda(1+\Omega))\left(\frac{\partial f}{\partial v}\right) = p_v + t_v - \lambda$$

$$(11)(P_q - t_q - \lambda(1+\Omega))\left(\frac{\partial f}{\partial r}\right) = p_r + t_r - \lambda$$

$$(12)\ (P_q - t_q - \lambda(1+\Omega))\left(\frac{\partial f}{\partial l}\right) = p_l + t_l$$

Optimal policies now are

$$t_q = p_d - p_z - \lambda(1+\Omega) \qquad t_v = p_z + \lambda$$
$$t_r = p_z - p_d + \lambda \qquad t_l = 0$$

Interestingly, a virgin materials tax appears to *still* be necessary, even with the standard. However, in one special case, it is possible for the optimal virgin tax to be zero. Notice first that λ is the shadow price of the constraint on *z* – i.e., the marginal effect on the firm's profits of decreasing Ω , or tightening the standard for a given output level. If the standard is set to generate the optimal level of *z* for a given level of output, then λ is equal to $-p_z$, the marginal social cost of *reducing z* by one unit. Substituting this for λ in the expressions above yields the following set of taxes:

$$t_q = p_d + p_z\Omega \qquad t_v = t_l = 0$$
$$t_r = -p_d$$

In this case, when the standard is set to generate the optimal level of manufacturing effluent for a given level of output, then a tax on virgin materials is unnecessary. There is still a deposit-refund required to achieve the optimal amount of disposal and it is equal to the marginal social cost of disposal, p_d. And importantly, an additional output tax of Ωp_z is required. The need for this last instrument arises from the fact that the upstream pollution standard is set per unit of output, thus necessitating an additional tax on output to generate the overall optimum. Thus, the overall output tax has a component to address the solid waste disposal problem, p_d, and a component to address the fact that the effluent standard is set per unit of output, Ωp_z. Contrary to the results in part A above, the output tax here is *increased* to address the upstream pollution problem. This is because the standard by itself cannot generate the optimal amount of output and effluent. This finding is related to that of Eskeland and Devarajan (1996) who argue for the use of output taxes in combination with technology standards to mimic the results achieved by a Pigouvian emissions fee. It is also related to Fullerton's (1997, p. 250) statement that both an "output effect" and a "factor substitution effect," which are embodied in a Pigouvian tax, are necessary features of any optimal pollution policy.

IV. Incorporating an Additional Upstream Externality from Energy Use

In this section, we address one final upstream pollution problem. We modify the firm's production function to include energy as an input. Firms are assumed to pay a price for energy, p_e, and that price is set competitively on the world market. There is also an externality from energy use -- say, damages from global warming resulting from carbon dioxide emissions, and the monetary value of these damages is $\phi(ne)$ with $\phi'(ne) > 0$ and $\phi''(ne) > 0$.[9]

The expression for net social surplus is now:

$$(13) NSS = \int_0^{nf(v,r,l,e)} P_q(s)ds - \int_0^{nr} c_r(x)dx - np_v v - np_l l - np_e e - \phi(ne) \\ - np_z\big(v + r - f(v,r,l,e)\big) - np_d(f(v,r,l,e) - r)$$

Maximizing *NSS* with respect to *v*, *r*, *l*, and *e* under the assumption that the market for the secondary material is in equilibrium, and therefore $p_r^* = c_r$, yields the same first-order conditions for *v*, *r*, and *l* that we derived above, equations (2), (3), and (4), and the following first-order condition for *e*:

$$(14) \left(P_q^* + p_z - p_d\right)\left(\frac{\partial f}{\partial e}\right) = p_e + \phi'$$

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[9] The emissions are assumed to be a function of energy input alone, and therefore only reducible through reduced energy use. This assumption is reasonable for the global warming problem since end-of-pipe abatement of CO2 is technologically infeasible. However, for other pollutants such as SO2 or NOx this formulation is inappropriate.

where P_q^* is the market-clearing price of output.

In the private market outcome, it is straightforward to show that a tax on energy equal to ϕ', together with the optimal taxes on v, r, and q necessary to address the solid waste disposal and manufacturing effluent externalities derived above, will lead to the social optimum. If energy cannot be taxed, however, it is possible to set taxes on the other inputs and output to achieve the same outcome. We derive these results now.

The profit-maximizing firm chooses v, r, l, and e so as to maximize the following (there remains a zero price for waste disposal and for z and there are no standards applied to z):

$$(15)\,\Pi = (P_q - t_q)f(v,r,l,e) - (p_r + t_r)r - (p_v + t_v)v - (p_l + t_l)l - p_e e$$

The first-order conditions are:

$$(16)(P_q - t_q)\left(\frac{\partial f}{\partial v}\right) = p_v + t_v$$

$$(17)(P_q - t_q)\left(\frac{\partial f}{\partial r}\right) = p_r + t_r$$

$$(18)\,(P_q - t_q)\left(\frac{\partial f}{\partial l}\right) = p_l + t_l$$

$$(19)(P_q - t_q)\left(\frac{\partial f}{\partial e}\right) = p_e$$

Assuming $P_q = P_q^*$ and $p_r = p_r^*$ (conditions that must hold to achieve the optimum) and solving for the taxes that achieve the optimum yields:

$$t_r = p_z - p_d - \left(\frac{\partial f / \partial r}{\partial f / \partial e} \right) \phi'$$

$$t_v = p_z - \left(\frac{\partial f / \partial v}{\partial f / \partial e} \right) \phi'$$

$$t_l = - \left(\frac{\partial f / \partial l}{\partial f / \partial e} \right) \phi'$$

$$t_q = p_d - p_z + \frac{\phi'}{\partial f / \partial e}$$

The form of the taxes is similar to the taxes we derived in section II except each now has an added component to address the energy-related externality. Each of the inputs except energy now receives a subsidy equal to the marginal external damage from energy multiplied by the marginal rate of technical substitution between that input and the energy input. The greater the marginal rate of technical substitution – i.e., the more easily substitutable the input is for energy – the larger the subsidy. The greater the marginal external damage from energy, the larger the subsidy. The tax on output is increased by an amount equal to the marginal external damage from energy divided by the marginal product of energy – i.e., the marginal energy-related external cost from an additional unit of output. Thus, the greater the energy-related damages from producing more output, the greater the necessary output tax.

These results are the same as findings in a recent paper by Fullerton and Wolverton (1997) who advocate a deposit-refund type of approach as a general alternative to Pigouvian taxes. They recommend a tax on output coupled with a subsidy to all "clean" inputs, which they call a "two-part instrument", in many settings where monitoring and enforcement costs associated with Pigouvian taxes are high.[10] The form of their subsidies and taxes, however, like ours, is quite complicated and depends on the form of the firm's production function. We discuss this problem and other practical issues in the next section.

V. Practical Issues

We derive alternatives to Pigouvian taxes when there is an upstream pollution problem associated with manufacture of a consumer product along with downstream, post-consumer solid waste disposal. The combined taxes and subsidies we derive in each of the scenarios are equivalent, in the context of our model, to Pigouvian taxes. To determine whether the alternative policies we derive would be more or less preferred to Pigouvian taxes *in practice*, however, we need to step outside the model framework and address questions associated with monitoring and enforcement. We also need to speculate about the administrative costs of the policies. These issues are likely to vary substantially across products and pollutants.

Taxing legal disposal of post-consumer waste, for example, clearly creates incentives for illegal dumping which could result in greater harm to the environment than would result with legal disposal methods. Monitoring and enforcing illegal dumping laws is often prohibitively costly. For this reason, our alternative recommendation of a deposit-refund is likely to be the most appropriate policy tool for managing solid waste disposal. Others have suggested the same approach to managing hazardous waste disposal (Hahn, 1988; U.S. Congressional Research Service, 1989).

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[10] See Costanza and Perrings (1990) for a similar recommendation. Neither study addresses multi-media or life-cycle pollution.

Industrial air and water pollution is more of an open question and likely to vary by pollutant and industry. In some situations, measuring actual industrial emissions can be difficult. For example, the determination of BOD levels from pulp and paper manufacturers and other sources requires a five-day incubation of an effluent sample. Results from this test must be modified to reflect the effects of temperature, sunlight, water movement and other factors not reproduceable in the laboratory. An advantage of our alternative policy prescription is that tracking virgin materials used in production and the amount of output produced, or product sales, could be easier and have less potential for error than trying to measure emissions.

Another consideration, for some types of pollution, is that the sources can be so small and dispersed that monitoring source-by-source emissions is extremely costly. Solvent emissions from neighborhood dry cleaners is one example. Macauley, Bowes, and Palmer (1992), in their assessment of this problem, recommend a deposit-refund system for solvent as an alternative to a Pigouvian tax. Our model suggests perhaps a tax on dry-cleaning services and the solvent input. Monitoring and enforcing these taxes might be noticeably easier than an emissions tax for two reasons: (1) dry cleaning sales are more easily tracked than emissions, and (2) solvent manufacturers could be assessed the solvent tax and there are far fewer of them than dry cleaners.[11]

On the other hand, there are situations in which monitoring and enforcement are likely to be less of a problem. For example, the availability of continuous emissions monitoring technologies have helped to make possible the adoption and implementation of the SO2 emission allowance trading program in the U.S. Monitoring has not been a problem in the program to date and has apparently facilitated cost-effective reductions in total emissions across all sources (Burtraw and Swift, 1996). In this case, opting for multiple taxes on inputs and outputs as an alternative is likely to have much higher administrative costs than the direct approach currently being used.

This also seems, to us, to be the case with respect to CO2 emissions from energy use in the production of consumer products. Emissions of CO2 from energy combustion are directly related to the density and the carbon content of the original fuel source (U.S. Department of Energy, 1995). Therefore, a tax designed to address CO2 emissions from fuel combustion could be applied directly to the oil refiner, natural gas well or coal mine. Fuel sources are subject to a number of taxes already and therefore the administrative mechanisms for collecting an additional environmental tax may be largely in place.

Nonetheless, political impediments to a carbon tax, at least in the United States, seem to be high. As a result, government policymakers are seeking CO2 emission reduction "credits" through other environmental policies, including solid waste-related policies. President Clinton's 1993 Climate Change Action Plan stated that "increased source reduction and recycling will save energy and money, cut greenhouse gases, reduce the need for natural resource extraction and help alleviate disposal problems" (Clinton and Gore, 1993, p. 17). The U.S. EPA (1997) recently completed a study quantifying the greenhouse gas emissions reductions associated with different solid waste policies throughout various product life-cycles.

Our results in the preceding section suggest that the costs of opting for these indirect approaches to reducing CO2 emissions are likely to be high. A serious drawback to the indirect approach is that the optimal subsidy for each of the non-energy inputs to production depends on the marginal rate of technical substitution between that input and energy –

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[11] Illegal solvent disposal by dry cleaners is a potential problem that would also need to be addressed. This is an additional upstream environmental problem that we would need to consider in our model – a cross-media

something that is likely to vary by product and individual manufacturer. Deriving and implementing such subsidies could be extremely difficult, if not impossible.

VI. Concluding Remarks

In this paper we explore the policy implications of a specific kind of multi-media pollution problem – upstream pollution resulting from manufacture of a consumer product along with downstream disposal of the post-consumer solid waste generated by that product. We showed that when Pigouvian taxes on the upstream pollutant and consumer waste disposal are precluded, the alternative policy set generally includes a tax on virgin material inputs as well as a tax on output and subsidy to recycling – i.e., a deposit-refund. In addition, the deposit-refund is lower than it would be in the absence of the upstream pollution problem. This suggests that providing incentives for source reduction – reducing raw material inputs to production – can lower the cost of achieving downstream environmental goals.

If production emissions are subject to a per-unit of output emissions standard, as is the case for most water and some air pollution, it is possible to set the standard and a product tax such that a virgin materials tax is not necessary. The product tax is always necessary to achieve the optimum, however, and the deposit-refund is still necessary to address the downstream disposal externality.

Finally, when there is an upstream externality related to energy use, such as CO2 emissions, we find that the optimal policy set includes a subsidy to all non-energy inputs and a tax on output, the same result reached by Fullerton and Wolverton (1997). In this setting, the optimal taxes and subsidies depend on the form of the individual firms' production

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pollution problem of the type addressed by Sigman (1996).

functions which greatly complicates the government's task of setting these policy parameters optimally.

As a general result, we find that alternatives to Pigouvian taxes do exist for life-cycle pollution problems. The taxes and subsidies we derive in each of our scenarios are equivalent to Pigouvian taxes in that they achieve the first-best socially optimal level of both the upstream pollution and downstream waste disposal. We find, however, that multiple policy instruments are necessary to address multiple pollution concerns – i.e., one instrument will not fully internalize both the upstream and downstream externalities. We also show that, in general, pollution standards which are set per unit of output, as many currently are, cannot obtain the social optimum but must be combined with an output tax.

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