Optimal Environmental Taxation

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ABSTRACT. Environmental assets that are prone to market failure include pastures, fisheries, and aquifers, but also the important assimilative capacities of waste sinks such as rivers, oceans, air and atmospheres to absorb and eliminate the residual by-products from consumption and production. In a first-best world, the services provided by these assets should be priced at marginal cost—for example using Pigouvian taxes where property rights cannot be assigned. And in a second-best world where government must use taxes to raise revenue, an extra tax should be levied on each as part of an optimal revenue-raising tax program.

Such environmental taxes will, in general, produce three distinct benefits. First, they will restore allocative efficiency. Second, they will appropriate the rents from exogenously supplied assets as a non-distorting source of public funds. And third, they will broaden the tax base. Our general equilibrium analysis indicates that second-best optimal environmental taxes will be higher, and optimal pollution level lower, than the Pigouvian analysis. Moreover, even in the absence of pollution damages, emissions taxes may be justified on tax efficiency grounds alone.

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I. Introduction

The principles of optimal revenue-raising taxation are among the oldest in the public finance literature dating back to Ramsey (1927), and the theory of optimal corrective taxation of externalities is also well-established and dates to Pigou (1947). Nevertheless, these two strands of theory have not been adequately integrated as evidenced by recent debate, awkward intuition, and conflicting conclusions about optimal taxation when pollution taxes interact with the existing revenue system (Sandmo 1975, Oates 1993, 1995; Terkla 1984; Lee and Misiolek 1986; Bovenberg and de Mooij 1994, Bovenberg and Goulder 1996, Parry 1995).

This paper attempts to integrate corrective environmental taxation and optimal tax theory to provide both a consistent framework for combining these two strands of theory and to shed light on recent controversies. Central to the approach taken here is a general equilibrium model in which the environmental resources themselves, rather than the metaphorical "externalities" that may arise from their use, are explicitly considered. We take as our starting point the view that natural environments such as the air, rivers, lakes, oceans, atmosphere, and subsoil systems represent public goods (or assets) that provide services and produce commodities. In particular, we emphasize the capacity of these "waste sinks" to absorb, store, or assimilate the residual by-products from production and consumption. These environmental assets also provide other services, such as clean air and water that protect human health, increased productivity of land or other resources, recreational amenities, and production of commodities such as fish or timber (Mäler 1985).

As with a fishery, pasture, forest, or other renewable resource, the assimilative capacity for waste disposal can be characterized as congestible public goods with capacity constraints. Pollution problems—or the misallocation of waste disposal services—can be seen as market failures that arise when property rights to the assimilative capacity of natural environments are neither assigned nor enforced. Unrestrained use of the assimilative capacity of environmental sinks constitutes a misallocation of the resource and will lead to the dissipation of their potential resource rents.

The intuition for the results presented below is straightforward. The assimilative capacities of natural environments represent services from exogenously provided assets. They are separate goods, and like other goods in the economy, they should be taxed directly as part of a broadly based tax program. Used at efficient levels, the Pigouvian price simply represents the unit cost of the waste disposal service, and thus is the appropriate price to which second-best revenue raising taxes should be added.

Moreover, like land, exhaustible resources, or other biological resources, the rents from these resources can be taxed without producing distortionary effects. Up to the Pigouvian tax rate, therefore, there are two benefits from taxing waste disposal, the restoration of allocative efficiency and the appropriation of rents for a previously free but economically valuable asset. When taxes on waste disposal are introduced in a revenue-neutral way, the combination of these two effects produces a "double dividend" by substituting nondistortionary taxes on resource rents for other distortionary taxes, the excess burden of the tax system is lowered. Moreover, for tax rates above the Pigouvian price, the welfare cost of taxation can be reduced further by substituting environmental taxes for preexisting taxes until the marginal excess burden of the two are equal. This broadening of the tax base constitutes a "third dividend."

The rationale and intuition of the model is developed in more detail in section II. Section III presents a general equilibrium model and results for optimal environmental taxation. Section IV discusses the double dividend hypothesis. Section V concludes.

II. Basis for conceptual model

It has long been recognized that the problem of environmental pollution stems from the unavoidable generation of residual byproducts inherent in virtually all production and consumption activities. The possibility of disposing of these residuals in a convenient environmental sink such as air, atmosphere, watercourse, or landfill, represents an important economic service to consumers and producers (Mäler 1985). Were such services unavailable, residual disposal would inevitably be more costly since individuals would be forced to dispose of waste in less convenient ways or ultimately to accumulate and store stocks of these residuals.

In addition, the considerable degree of substitutability and flexibility that exists between and among waste sinks and between other goods and waste sinks has not always been recognized or taken account of. Residuals may be recycled or discharged directly into environmental media with or without modification; although most residuals can be transformed into forms that make it possible to dispose of them in numerous alternative media (Kneese 1971). For example, through the application of equipment and energy, most substances can be removed from water or air streams and transformed into residuals that can be disposed of in solid form or reused (Kneese 1971). Furthermore, residuals may be transported and disposed of in distant environmental sinks where pollution costs may be lower due to higher assimilative capacity, lower current flows, or their remoteness from human activity. The degree of substitutability is often surprisingly large (Cavendish and Anderson 1994).

Natural environments often provide several kinds of services in addition to waste assimilation, such as clean air and water that protect human health, amenity benefits consumed directly, by enhancing the productivity of other assets (i.e., land, forests), and commodities such as fish and game. They represent neither "pure" public or non-rival goods nor strictly rival goods, but rather may be characterized as "congestible public goods" which, like highways, beaches, aquifers, pastures, or fisheries, can become congested due to stock effects beyond some level of use.

The pollution example is different than other congestible natural assets where congestion costs are reciprocal. Here there are two distinct kinds of services being provided: waste disposal and amenities. In this case, the stock effect related to the waste sink's assimilative capacity means that above some threshold of residual flows there will be a deterioration of the environment's other services (e.g., unhealthy air, unswimmable water, loss of protection from solar radiation, loss of output in forestry, fisheries, or agriculture). The conflict arises, not between competing users of the environment as a waste sink, nor among competing users of the environmental amenities, but rather between those who dispose of waste and those who enjoy its other services (e.g., protection of human health, amenities, or other goods such as fish). The congestion costs are asymmetric: the level of waste flows may reduce amenity benefits, but increased consumption of the amenity services does not affect the sink's assimilative capacity in a direct way.

Pollution problems, therefore, are best understood as market failures that occur when the property rights associated with use of a natural environment--either for waste disposal or its amenity benefits—are neither assigned nor enforced. Without such property rights the services of these exogenously supplied environmental resources will be misallocated and their rents will be dissipated.

This characterization of the role of environmental resources in the economy differs considerably from the more familiar notion of an “externality,” the conceptual basis and precise definition of which has long been elusive. The literature contains numerous definitions and classes of "externalities" (Bator 1958; Buchanan and Stubblebine 1962; Coase 1960; Meade 1952), but there is no straightforward, intuitive, or standard definition. Indeed, Baumol and Oates (1988) observe that for a definition of an externality "one is left with the feeling that we still have not captured all its ramifications"(p. 14). They point out that in several seminal works on the subject, externalities are not defined formally or are defined not in terms of what they are, but what they do (Baumol and Oates 1988, p. 16). Others have suggested that the notion of an externality is not a useful term at all (Cheung 1970), or even that it is "a vacuous and entirely unhelpful term, and [should] be replaced by the more general term *inefficiency* with no loss of content" (Randall 1983, p. 132).[1]

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[1] In some cases the poor fit between the metaphor and the resource or medium has led to strained attempts to generalize the theory by defining and distinguishing between "depletable externalities" and "undepletable externalities" (Baumol and Oates, 1988) rather than by recognizing the difference between environments for which use is excludable and non-excludable.

In a useful interpretation, however, Arrow (1969, cited in Baumol and Oates 1988, p. 16) recognizes the need to associate externalities “with the absence of some markets for the trading of *items* affecting the welfare of economic agents.” Nevertheless, most applications have tended to define away the *item* itself, drawing economists’ attention away from the environmental medium at the core of all such allocation problems. Instead, an externality has become a vague and inflexible link between the consumption of a particular “dirty” commodity or input, and a negative effect on other economic agents. It thus bypasses completely the environmental resource itself, its assimilative capacity, and—most importantly for our purposes—the degree of substitutability between commodities and among environmental waste sinks.

For the analysis here, recognizing the role of waste disposal in utility is essential. When residual wastes are generated and the alternatives to environmental waste disposal are limited or higher cost (such as storing the waste indefinitely) these environmental services contribute to well-being. The household production function approach to utility has been recognized to be advantageous for environmental economics applications (Mäler 1985, p. 15). In this model “commodities” that provide utility directly are produced within the household by combining purchased market goods, other services and some of the household's own time (Lancaster, 1971; Michael and Becker, 1973), The need to explicitly model the household production function directly is avoided because one can substitute it into the utility function to get the derived utility function in terms of goods, time, and environmental variables (Michael and Becker 1973).

In addition to the range of alternatives for waste disposal noted at the beginning of this section, the household production function approach recognizes still additional substitution possibilities involving consumer choices provided for within the household production function. For example, individuals may derive utility directly from maintaining bodily warmth. Indirectly, the inputs into the household production function that produce bodily warmth may include various combinations of fossil fuels, local atmospheric disposal of residuals, electricity, warm clothing, and home insulation. Even though fossil fuels and waste generation are strong complements, a range of substitution possibilities may exist between alternative sources of energy (natural gas, electricity, solar), alternative waste sinks (local versus more distant ones), and substitutions of home insulation, catalytic converters, wool sweaters, etc. Even if the marginal rate of technical substitution is zero, substitutability at the level of the derived utility function may be greater than zero given alternative waste sinks, recycling possibilities, indefinite storage, or the application of technologies that reduce, modify, or transform the residuals.

III. The general equilibrium model

In order to describe the problem rigorously, consider a world with n consumption goods where producer prices are $\mathbf{q} = (q_0, q_1, q_2, ..., q_n)$ for market commodities 0, 1, ..., n, and where the **q**s reflect constant unit costs of production. In addition let consumer prices be $\mathbf{p} = (p_0, p_1, p_2, ..., p_n)$, where producer prices will differ from consumer prices owing to the government's use of excise taxes $\mathbf{t} = (t_0, t_1, t_2, ..., t_n)$ to raise revenue R. Therefore $p_i = q_i + t_i$. Consider good zero to be leisure time (where time endowed is allocated to leisure or labor supply), and set $q_0 = -1$.

For the case of many identical consumers, let the household's utility function be $U(x_1, x_2, ... x_n)$ be represented in terms of the derived utility function for the *n* consumption goods x_is, and a vector of quantities of its own time, and write the utility maximization problem for the n consumption commodities according to the utility function $U(x_0, x_{1_1}, x_2,...., x_n)$ where x_i is the amount of the ith good consumed for goods $x_0, x_1, x_2, ... x_n$, subject to the budget constraint of $p_0x_0 + p_1x_1 + ...p_nx_n = 0$ (Michael and Becker, 1973).

In addition to these commodities, however, assume also that there are *m* environmental assets which produce two distinct kinds of services--waste disposal services and amenity services. The services from these natural environments must also enter the economic model, and they do so in two ways. First, given the capacity of each of the *m* environments to assimilate or store waste, let w_1, w_2, ..., w_m represent the disposal of waste in each corresponding environment such as a specific lake, river, ocean, local air shed, landfill, etc.)[2] Second, each of these natural environments is also assumed to have an amenity value a_j (health, recreation, ecosystem function) that enters the individual utility function separately as a_1, a_2, ..., a_m.

Because these environmental assets are assumed to be congestible public goods, the amenity services a_j of waste sink j may be reduced due to the stock effect arising from the flow of waste services w_j. Thus, the services from each environmental assets may be non-rival up to some point beyond which the congestion costs of one service (waste disposal) affects the flow of the other service (amenities). For simplicity we have limited the congestion costs to their direct amenity value to consumers, but these congestion costs could also be modeled to impose costs on production by reducing the productivity of other factors (e.g., damages from water pollution on a fishery, climate change or air pollution on agriculture, etc.).[3]

A. Optimal taxation in general equilibrium

Because both the waste disposal and amenity services are non-rival and non-exclusionary, we assume initially that waste services are unpriced ($q_j = 0$ for j = 1, ..., m), and further that that while taxation of waste disposal services is feasible, charging fees for environmental amenities is not (asking people to directly pay for breathing clean air or for enjoying protection from atmospheric ozone is assumed to be infeasible, although this need not always be the case). The level of wastes generated through consumption of market

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[2] For simplicity, assume that only one kind of waste (e.g., sulfur dioxide) is disposed of in any given sink, or alternatively that different w_js may represent different kinds of waste deposited in the same waste sink (e.g., the atmosphere) but whose effects are independent.

[3] Restricting our analysis to direct amenity effects on utility does not limit the generality of our conclusions. A model where pollution affected factor productivity, or where the demand for waste disposal was in the form of derived demand from firms for an input into production would give similar results as has been demonstrated in the public finance literature (Diamond and Mirrless 1971). Indeed, since we are here considering the household to be a production unit, and where labor (leisure) is both an input into production and a good, then the differences between this model and a production-oriented one are reduced to differences in the boundaries of the household and the firm.

commodities varies across goods, as does the assimilative capacity of the different waste sinks, their amenity value, and the sensitivity of that amenity value to the level of waste. For simplicity it is assumed that waste generated comes from within the household production function and not from the production of market goods.

Assume that the number of individuals and the costs of coordinating individual choices imply that each individual takes the congestion costs for each of the m environments as given. Then the individual optimization problem is

$$\text{Max } U(x_0, x_1, x_2, ..., x_n, w_1, w_2, ..., w_m, a_1, a_2, ..., a_m), \qquad [9]$$

subject to $\sum_i p_i x_i = 0$ and $\sum_j p_j w_j = 0$ for i = 0, 1, 2, ... n; j = 1, 2, ..., m.

and where we assume for the moment that p_j, the price charged for waste w_j in sink j, is equal to zero for all waste disposal j = 1,..., m.

We can formulate the optimal tax problem as

$$\begin{aligned} &\underset{p}{\text{Max}}[\underset{x,w}{\text{Max}}\,\text{U}(\mathbf{x},\mathbf{w},\mathbf{a}) \text{ subject to } \mathbf{p}_{\text{X}}\cdot\mathbf{x} + \mathbf{p}_{\text{W}}\cdot\mathbf{w} = 0] \\ &\text{subject to } (\mathbf{p}_{\text{X}} - \mathbf{q})\cdot\mathbf{x} + \mathbf{p}_{\text{W}}\cdot\mathbf{w} = \text{R} \end{aligned} \qquad [10]$$

It is useful to approach such problems by way of the dual (see Auerbach, 1985; Diamond and Mirrlees, 1971) and define the indirect utility function as V(U(**x, w, a**)). Then we have

$$\underset{\mathbf{p}}{\text{Max}}\,V(\mathbf{p},\mathbf{a}) \text{ subject to } (\mathbf{p}-\mathbf{q})\mathbf{x} = \text{R} \qquad [11]$$

For the Lagrangian constrained optimization problem

$$V(\mathbf{p},\mathbf{w},\mathbf{a}) - \mu[\text{ R} - (\mathbf{p}_{\mathbf{x}} - \mathbf{q})\cdot\mathbf{x} - \mathbf{p}_{\mathbf{w}}\mathbf{w}] \qquad [12]$$

where $\partial V / \partial \mathbf{a} = \partial U / \partial \mathbf{a} \Big|_{\mathbf{x}=\mathbf{x}(\mathbf{p}_X,\mathbf{p}_W,\mathbf{a})}$, and the first-order conditions with respect to each price are

$$-\lambda x_i + \sum_{j=1}^{m} h \frac{\partial U}{\partial a_j} \cdot \frac{da_j}{dx_i} \cdot \frac{\partial x_i}{\partial p_i} + \mu \left[\sum_{k=1}^{n} t_k \frac{\partial x_k}{\partial p_i} + \sum_{j=1}^{m} t_j \frac{\partial w_j}{\partial p_i} + x_i \right] = 0, \text{ for i} = 1,2,\ldots, \text{ n.} \qquad [13]$$

for each commodity x, and

$$-\lambda w_j + \sum_{j=1}^{m} h \frac{\partial U}{\partial a_j} \cdot \frac{da_j}{dw_j} \cdot \frac{\partial w_j}{\partial p_j} + \mu \left[\sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial p_j} + \sum_{k=1}^{m} t_k \frac{\partial w_k}{\partial p_j} + w_j \right] = 0, \text{ for j} = 1,2,\ldots, \text{ m.} \qquad [14]$$

for each waste sink w, and where λ = d***V***/dy is the marginal utility of income for consumers. Note that in equation [13] the second term in the left-hand side, which capture a physical relationship not a behavioral one, will equal zero since ${}^{da_j}\!/_{dx_i} = 0$: the flow of amenity services is not directly influenced by commodity consumption. In [14], however, the physical affect of waste disposal on amenities, ${}^{da_j}\!/_{dw_i}$, may be non-zero due to the stock effects of waste disposal. Because the environmental amenity is a non-rival good, the marginal utility is multiplied by the population, *h*. Rearranging terms to isolate t for each commodity, we can write

$$\sum_{k=1}^{n} t_k \frac{\partial x_k}{\partial p_i} = \left(\frac{\lambda - \mu}{\mu} \right) x_i - \frac{h}{\mu} \sum_{j=1}^{m} \frac{\partial U}{\partial a_j} \frac{da_j}{dx_j} \frac{\partial x_j}{\partial p_i} - \sum_{j=1}^{m} t_j \frac{\partial w_j}{\partial p_i} \text{ for i = 0, 1, 2,... n} \qquad [15]$$

and for each waste sink we can write

$$\sum_{k=1}^{m} t_k \frac{\partial w_k}{\partial p_j} = \left(\frac{\lambda - \mu}{\mu} \right) w_j - \frac{h}{\mu} \sum_{k=1}^{m} \frac{\partial U}{\partial a_k} \frac{da_k}{dw_k} \frac{\partial w_k}{\partial p_i} - \sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial p_j} \text{ for j = 1, 2,... m.} \qquad [16]$$

As it is unnecessary, and increasingly cumbersome, to maintain a separation between the x’s and the w’s, let us define as the set of “z” goods the combined set of n market goods plus the m waste sink services so that z_i will represent the quantity of the ith good for i = 0, 1, 2,..., n, n+1, n+2, ..., n+m and having prices $p_i = p_1, p_2, \ldots, p_n, p_{n+1}, p_{n+2}, \ldots p_{n+m}$. In that way, [15] and [16] can be replaced by a single equation

$$\sum_{k=1}^{n+m} t_k \frac{\partial z_k}{\partial p_i} = \left(\frac{\lambda-\mu}{\mu}\right) z_i - \frac{h}{\mu} \sum_{j=n+1}^{m} \frac{\partial U}{\partial a_j} \frac{da_j}{dz_j} \frac{\partial z_j}{\partial p_i} \quad \text{for i = 0, 1, 2,... n+m.} \qquad [17]$$

And given that the $\partial z_j/\partial p_i$s are the elements of the Slutsky matrix, we can isolate t_i on the left-hand side by using Cramer's rule to get

$$t_i = \sum_{k=1}^{\text{n+m}} \left[\left(\frac{\lambda-\mu}{\mu}\right) z_k - \frac{h}{\mu} \sum_{j=n+1}^{\text{m}} \frac{\partial U}{\partial a_j} \frac{da_j}{dz_j} \frac{\partial z_j}{\partial p_i} \right] \frac{\mathbf{S}_{ki}}{\Delta} \text{for all I = 1, 2, ..., n+m.} \qquad [18]$$

where the $\mathbf{S}_{ki}$s are the cofactors of the Slutsky matrix **S** and Δ is its determinant. The inverse of the Slutsky matrix can be decomposed to write this as

$$t_i = \sum_{k=1}^{\text{n+m}} \left(\frac{\lambda-\mu}{\mu}\right) z_k \frac{\mathbf{S}_{ki}}{\Delta} - \frac{h}{\mu} \sum_{j=n+1}^{\text{n+m}} \sum_{k=1}^{\text{n}} \frac{\partial U}{\partial a_j} \frac{da_j}{dz_j} \frac{\partial z_j}{\partial p_k} \cdot \frac{\mathbf{S}_{ki}}{\Delta} \qquad [19]$$

By the rules for expansion of cofactors of determinants, we know that

$$\sum_{k=1}^{\text{n}} \frac{\partial z_j}{\partial p_k} \mathbf{S}_{ki} = \begin{cases} 0 & \text{for k} \neq \text{i} \\ \Delta & \text{for k = i} \end{cases}. \qquad [20]$$

So that we can write the optimality conditions as

$$t_i = \sum_{j=1}^{\text{n+m}} \left(\frac{\lambda-\mu}{\mu}\right) z_j \frac{\mathbf{S}_{ji}}{\Delta} - \frac{h}{\mu} \frac{\partial U}{\partial a_i} \frac{da_i}{dz_i} \quad \text{for i = 1, 2, ..., n + m.} \qquad [21]$$

although for i = 1 to n, the market commodities, this relation collapses to

$$t_i = \sum_{j=1}^{\text{n}} \left(\frac{\lambda-\mu}{\mu}\right) x_j \frac{\mathbf{S}_{ji}}{\Delta} - \frac{m}{\mu} \frac{\partial U}{\partial a_i} \frac{\partial a_i}{\partial x_i} \quad \text{for i = k + 1, k + 2, ..., n.,}$$

[22]

since when $i \leq n$ the second term on the right hand size equals zero because the consumption of a market commodity has no direct, physical effect on the amenity services provided by the environment.

This result supports a general, and seeming intuitive, conclusion: waste disposal is a separate good, and like any other good it should be priced at marginal cost (the second term on the right hand side in [21]), and in a second-best world, they should also be taxed as part of an optimal tax program (the first term on the right hand side of [21]).

The magnitude of the optimal corrective tax is an empirical question. Moreover, in either case--waste disposal services or market commodities--the first term on the right-hand side of [21] or [22] may, indeed, be negative, in which case it would be optimal to subsidize consumption by pricing the good (waste disposal) below its unit cost (Pigouvian price). But *a priori* there is no reason to believe this to be more likely for waste disposal than it is for any other good in the economy. The general theoretical conclusion--with neutral assumptions about the sign and magnitude of the elements of the Slutsky matrix--is that the optimal tax will exceed the Pigouvian price.

B. Results under restrictive assumptions

Results like those in [21] and [22] are not transparent and are thus difficult to interpret. Such results have sometimes been simplified by making the assumption that **S** is diagonal (Auerbach 1985; Sandmo 1975), and in addition by defining ϕ to equal λ/μ, the ratio of the marginal utility of income to the marginal cost of raising a dollar of revenue. We divide through by p_i, then substitute for p_i in the second term of the right-hand side the identity that will hold assuming allocative efficiency that $p_j \lambda = \partial U / \partial z_j$ for $j \leq n$. We therefore can write the optimal tax conditions as:

$$\theta_i = (1-\phi)\frac{-1}{\varepsilon_{ii}} - \phi h \frac{\frac{\partial U}{\partial a_i}\frac{da_i}{dz_i}}{\frac{\partial U}{\partial z_i}} \quad \text{for i = 1, 2, ..., n+m} \qquad [23]$$

where $\theta_i = t_i/p_i$. The interpretation of this result is more transparent (but potentially less useful for our purposes). In this case, for the *m* environmental sinks, it is important to recognize that $\theta_i = 1$ since waste disposal services were initially unpriced. Therefore, since $p_i = q_i + t_i$, and $q_i = 0$ for $i > n$, the tax rate and price level will always be equal so that θ_I will always equal 1. The first term on the right hand side, the distortionary component, reflects the well-known inverse elasticity rule for optimal taxation. The second term, which is the corrective component of the tax, will equal zero for market commodities since consumption of these goods has no direct (physical) effect on the availability of amenity services.

For waste disposal services the second term on the right hand side (excluding ϕ) represents the ratio of the marginal congestion cost (the marginal utility of the physical effect of waste disposal on the flow of amenity services) to the marginal utility of waste disposal (the behavioral relation). In a first-best world where raising revenue is costless (if $\phi = 1$), then the first term drops out and the fully optimal environmental tax will be given by the second term, the "first-best" Pigouvian price.

For cases where $0 < \phi < 1$ the interpretation of this optimality condition [23] is less straightforward, however. We can observe that the left-hand side of the relation is constant and always equal to one, as explained above. The two factors $(1-\phi)$ and ϕ are simply weights summing to one which are applied to the relative magnitudes of the distortionary component and the corrective component of the environmental service. Although it is tempting to interpret this relation as a weighted average of the first-best Pigouvian tax and the Ramsey tax, but this would be incorrect.[4] The apparent separability of the two terms in [21] is only an analytical one. All the prices, quantities, and elements of **S** are interdependent and so the optimal tax rates depend on the actual equilibrium; and symmetrically the actual equilibrium depends on the optimal tax rates.

For example, we can see that the corrective component is equal to the marginal social damage from pollution divided by the marginal utility of waste disposal. Note that as ϕ declines when initially equal to 1, the weight on the first term $(1-\phi)$ rises proportionally faster

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[4] This has been the interpretation found elsewhere in the literature; for example, in Sandmo (1975).

than the decline in the weight on the second term, so long as $|\varepsilon_{ii}| < 1$. In order for the sum of the two components to equal one, the second term must fall. The only way for this to occur is for the marginal pollution damage to decline, which implies a lower, not a higher, level of pollution. Numerically, we can see that if ϕ were to change from 1.0 to 0.9, the first term on the right hand side will become greater than 0.1. In order for the two terms to sum to 1, the second term being weighted now by 0.9, must decline below 1.0 for the two components to sum to 1. The only way for this to occur is for the optimum to shift to a lower level of pollution, implying a higher total tax rate on waste disposal. It follows that the higher is ϕ, the lower is the optimal level of pollution, and the higher is the efficiency gains from taxing environmental waste disposal. Exactly like other goods in the economy, the optimal distortionary tax will raise the price of waste disposal above its unit cost and the quantity demanded will decline.

In the special case where the environmental amenity is unaffected by waste disposal—where there are no congestion costs for waste flows below the assimilative capacity—then the numerator of the second term is zero and it drops out. That does not lead, however, to the conclusion that the optimal tax on waste disposal is zero. According to [23] the optimal tax will revert to Ramsey prices -- the inverse elasticity rule. Since $\theta_i = 1$, we can see that this will hold when $\varepsilon_{ii} = (1-\phi)$ which is equal to $(\mu - \lambda)/\mu$, the marginal excess burden of taxation. Therefore even in the absence of congestion costs, a positive tax on waste disposal will be optimal since the own-price demand elasticity, $\varepsilon_{ii} = \frac{p_i}{x_i} \cdot \frac{\partial x_i}{\partial p_i}$ will initially be zero when starting at zero price and rise gradually as the tax rate increases. The intuition for this is explained below.

IV. Triple Dividend

The literature on the public finance ramifications of environmental taxation can be divided into three phases. First, the original work on environmental taxation by Pigou (1938) and others ignored the question of how revenues from corrective taxes might be used. They assumed for simplicity that revenues are returned lump-sum to the economy. Second, a number of economists explored the question of whether using these tax revenues to finance equal reductions in revenues from existing taxes might produce a secondary benefit—a double dividend—by lowering the excess burden of the overall tax system. These analyses include early contributions by Sandmo (1975), Ng (1980), and Terkla (1984), and later by Lee and Misiolek (1986), Oates (1993), Pearce (1991), and Repetto et al (1992). The "double dividend hypothesis" implies that a revenue-neutral substitution of pollution taxes for pre-existing distortionary taxes will be welfare enhancing both because it achieves more efficient levels of pollution, and second because it reduces the excess burden of the tax system.

The third and most recent phase of this literature, however, casts doubt on the existence of a double dividend (Bovenberg and Mooij 1994; Bovenberg and van der Ploeg 1994; Parry 1995; Bovenberg and Goulder 1996). These authors suggest that while revenue recycling of pollution tax payments may be preferred to a lump-sum transfer, it is unlikely that these gains from substituting pollution taxes for other taxes would more than offset the additional distortionary costs of the pollution tax. They conclude that environmental taxes exacerbate rather than alleviate distortions because of their interactions with pre-existing taxes. Thus, the second-best optimal pollution tax is lower than the marginal environmental damage of pollution.

These conflicting conclusions are symptomatic of the underlying problem of the way in which public finance theory and environmental tax theory have been integrated. They appear to arise from the differences between optimal tax theory which correctly models prices and quantities of goods and services, and environmental tax theory which attempts to put prices on “external effects” rather than explicitly modeling the relevant environmental assets, goods, or services. Indeed, the notion of a double dividend has generally not been well enough defined or understood in the literature. And distinctions between the ‘strong version’ and weak versions’ have been developed without much attention to the question of why either version makes sense (Bovenberg and Goulder 1996; Goulder 1995).

When the environmental assets themselves are introduced into the model, one can easily recognize three distinct benefits from environmental taxation.

A. Allocative efficiency and rents appropriation

First, as Pigou recognized, environmental taxation can be used to achieve allocative efficiency in the case of pollution (or fishing, grazing, highway congestion, etc.). When the revenues from environmental taxation are used to finance reductions in preexisting taxes, the intuition for a “double dividend” is straightforward. The assimilative capacity to store, absorb, or assimilate waste in a given environmental waste sink is an exogenously supplied natural asset, and the pure rents from these services can be taxed away without distortion. Environmental waste sinks tend to be assets where property rights failures lead to misallocation of resources, and the dissipation of resource rents. By introducing a Pigouvian tax on waste disposal, government has effectively appropriated the resource, allocated it efficiently, and appropriated the rents. Because these rents are non-distorting, they will reduce the excess burden of the tax system if substituted for pre-existing distortionary taxes.

The appeal of taxing pure rents from exogenously supplied resources is a well-known and long-established part of the literature on the taxation of exhaustible resource rents (Gray 1914, Gaffney 1967, Dasgupta and Heal, 1979). The analysis presented above holds for other kinds of environmental services and other congestible public goods as well, whether they are supplied by nature or produced as public projects. An ocean fishery, for example, constitutes an exogenously provided congestible public good and taxing the rents from optimal harvesting of a fishery (i.e., by auctioning individual transferable quotas) would represent the appropriation of rents and produce the same benefits as indicated for a waste sink's assimilative capacity. Congestion pricing of highways or auctioning licenses to use segments of the electromagnetic spectrum are other examples where the appropriation of these rents can be used to improve the efficiency of the tax system.

In some cases of course, direct taxation of waste disposal may not be practical--in the same way that taxing many environmental amenities is not practical. In such cases, however, Pareto optimality may nevertheless be achieved through a set of indirect taxes on those commodities or inputs that have an effect on the amount of the externality produced (Holtermann, 1976).[5]

B. Broadening the tax base

In addition to the allocative efficiency and rent appropriation benefits which justify pollution taxes up to the Pigouvian rate, an even higher tax rate—above the Pigouvian price—will generally be required to achieve optimal taxation in a second-best world. The second terms of [21] and [23] confirm the conditions for allocative efficiency in waste disposal. But the first term indicates that a broadly-based optimal tax program will include taxes on waste

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[5] For example, if it is difficult to tax carbon emissions directly, the same result and incentives may be achieved by differential taxation of energy sources (coal, gas, biomass, solar) according to the net amount of carbon they emit when used. The result will be equivalent to a direct tax on carbon emissions (in the same way that public finance theory recognizes that proportional taxes on all commodities are equivalent to a tax on exogenous

disposal that will be <u>additional</u> to the price required to achieve allocative efficiency. By taxing waste disposal (above unit cost), environmental taxes broaden that tax base.

The intuition of this “triple dividend” argument can be understood with the help of a thought experiment. Consider the welfare implications of two alternative policies intended to achieve optimal pollution in a second-best world by solving the property rights failure directly—by introducing tradable emissions rights. First, assume that the efficient level of pollution is attained with the free distribution of the optimal number of permits. Given a competitive market in permits, this will achieve allocative efficiency and produce the full social benefits normally expected with a Pigouvian tax since the permit price will be expected to equal the Pigouvian price. The first social benefit.

Now, in the second part of the thought experiment, assume a similar intervention. In this case, however, assume the permits are auctioned off and the revenues are used to finance marginal reductions in existing tax rates on other goods and services. This second social benefit arises from the appropriation of the resource rents which are used to substitute for distortionary taxes.

In the third part of the thought experiment we can see that with emissions permits trading at efficient prices, it will now make sense to tax the sale of these permits along will all other goods and services as part of a broadly based tax program. By taxing the purchase of emissions rights, and consequently lower marginal tax rates on preexisting taxes, this will broaden the tax base and lower the welfare cost of taxation. The third dividend.

If the preexisting tax is an income tax is in place, then the purchase of pollution rights are being taxed indirectly at the same rate as all other goods. Since the revenues from the sale

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income). This point reinforces the importance of carefully identifying the good or service being taxed (such as of pollution rights have substituted for pre-existing tax revenues, the marginal income tax rate must fall.

In the income tax case, the two examples are similar if we assume that when the pollution permits are given away, they are given to a single person who then sells them all. If that were the case, then it is easy to see that the only difference is who appropriates the resource rents—the individual or the government. Auctioning the permits will be welfare enhancing so long as the revenues are recycled, and so long as the marginal cost of raising a dollar of revenue in the tax system is higher than the marginal utility of income. Again, this result is well known in the exhaustible resources literature.

C. Taxing when pollution is not costly

Even in this case where there are no pollution damages, and the Pigouvian price is zero, it may still be optimal to tax waste disposal over the range of tax rates for which the marginal excess burden is lower than that of pre-existing taxes. If waste disposal is initially free, the first increment of a tax will be over a range where demand is very inelastic. Hence, according to the inverse elasticity rule in [23], this tax should be raised until the inverse of the elasticity is similar to those of other taxed goods.

Thus this triple dividend has the potentially attractive policy implication that a specific environmental tax can be justified solely on the basis of improving the efficiency of the overall tax system, thus making the burden of proof about the environmental damages less crucial in justifying a corrective tax. A zero tax on environmental waste disposal that is initially unpriced will never be optimal (ignoring transaction costs) even in the absence of pollution damages

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waste sink services as opposed to fossil fuels) as distinct from other complements.

because an initial incremental tax will always produce positive revenue and negligible excess burden--since ε_{ii} in [23] will initially be zero.

D. Tax interactions

Recent debate surrounding the validity of the double dividend hypothesis has focused on the interaction between environmental taxes and other distortionary taxes. Analyses including Bovenberg and deMooij (1994), Bovenberg and van der Ploeg (1994), Parry (1995), and Bovenberg and Goulder (1996) claim to refute the double dividend hypothesis. In the presence of preexisting distortionary taxes, they argue, environmental taxes are more costly than existing taxes because they exacerbate existing distortions and, as a result, the optimal environmental tax rate lies below the Pigouvian level. This "tax interaction hypothesis" appears to have been quickly accepted as the correct view.

The general result in [21] above, however, is a comprehensive result and should encompass all relevant considerations of tax interactions. The cofactors $\mathbf{S}_{ji}$ account for all cross-price effects between relevant pairs of goods on each good's optimal tax. The influence of "tax interactions" on the optimal environmental tax rate is thus an empirical question sensitive to assumptions about the substitutability among goods. Yet these general results have been at hand since Ramsey (1927), and issues such as the welfare implications of direct versus indirect taxes have also been well established in the literature (see, for example, Harberger, 1964; and Little, 1951). So what makes environmental taxation different? In principle, nothing.

What gives rise to the tax interaction hypothesis, which purportedly alters the well-known Ramsey formulas for optimal commodity taxation (Bovenberg and Goulder 1996), is an implicit, and quite restrictive, assumption in their models which leads directly to the rejection of the double dividend hypothesis. By constructing models where "externalities" arise in constant proportion to the consumption of a dirty good (where a dirty good "has an externality"), the relationship between a market good and the services of an environmental waste sink are implicitly, and unwittingly, constrained to fixed proportions. Fixed proportions between two goods, however, amounts to assuming the two are perfect complements, which, in all relevant senses, is the same as saying they are the same good. The essence of the tax interaction hypothesis amounts to asking the question, Does it make sense to tax the same good twice? The answer, of course, is no. Intuitively, if a good is taxed optimally once, then a "second" tax on the same good will not be optimal.

How this alters the results in [21] is not obvious due to the lack of transparency in the sign and magnitude of the cofactors $\mathbf{S}_{ji}$. The more transparent relation in [23] is not helpful either since, by assuming that the cross-price effects are zero, it assumes away the tax interactions that are of interest. The pivotal role of the substitutability between market goods and waste disposal can be seen by augmenting the usual three-good model to include waste disposal as a fourth good, and by making just a few simplifying assumptions to make the result easy to interpret. Assume therefore a model with four goods: leisure (z_0), a "clean" good (z_1), a "dirty good" (z_2), and waste disposal services (z_3). Assume leisure is the untaxed good, and that the usual property rights failures that give rise to excess pollution have been resolved with the auction of tradable permits for waste disposal in the optimal amount. By introducing this assumption—a kind of Lindahl equilibrium with government as proprietor—it follows that a competitive market for waste disposal will result in the permits being sold at the Pigouvian price. For good z_2, the “dirty good”, the second term of [21] is eliminated, so that we have [22] holding for all three goods.

For this model, the optimal taxes in [22] can be expressed more explicitly as

$$t_1 = \kappa[z_1(S_{22}S_{33}-S_{23}S_{23})-z_2(S_{12}S_{33}-S_{32}S_{31})+z_3(S_{12}S_{23}-S_{22}S_{13})]$$

$$t_2 = \kappa[-z_1(S_{21}S_{33}-S_{31}S_{23})+z_2(S_{11}S_{33}-S_{31}S_{13})-z_3(S_{11}S_{23}-S_{132}S_{12})] \qquad [24]$$

$$t_3 = \kappa[z_1(S_{21}S_{32}-S_{31}S_{22})-z_2(S_{11}S_{32}-S_{12}S_{31})+z_3(S_{11}S_{22}-S_{21}S_{12})]$$

where $\kappa = (\lambda-\mu)/\mu\Delta$ and the S_{ij} are the cross partial derivatives. These formulae are generic and, thus, should hold for any three-good model with or without an environmental good. It follows that the question, When an optimal tax on a good will be negative? is an empirical question about the values of the S_{ij}s. For example, in a well-known analysis of a model with just two goods, Harberger (1964) has shown that the conditions that must prevail in order for an optimal tax to diverge significantly from equal percentage taxes are unlikely.

The aim here is to assess t_3, the tax on waste disposal, and to see how the optimal tax will be affected by assuming that Z_3 is consumed in fixed proportions with z_2 ($z_2 = \beta z_3$). Given that the sign and relative magnitude of the optimal tax equations above are ambiguous, we will simplify by making the ostensibly neutral assumption that the partial cross-price effect between the clean and dirty good is zero ($S_{12} = S_{21} = 0$). With this restriction, the optimal tax on z_3 becomes

$$t_3 = \kappa[z_1(-S_{31}S_{22})-z_2(S_{11}S_{32})+z_3(S_{11}S_{22}) \qquad [25]$$

This relation is still of ambiguous sign as the first term is indeterminate, whereas the second is strictly negative and the third is strictly positive. But we can now ask the question, What will the optimal tax rate be if the “dirty good” and “waste disposal” are consumed in fixed proportions? Fixed-proportions implies not only that z_2/z_3 is a constant, but also that S_{22} is related to S_{23} by the same proportionality constant since

$$\partial z_3 / \partial p_2 = \partial z_2 / \partial p_2 \cdot \partial z_3 / \partial z_2 = \partial z_2 / \partial p_2 \cdot \frac{z_3}{z_2}$$

Thus we can write $S_{22} = S_{23}(z_2/z_3)$. Since we have already assumed that $S_{12} = 0$, then it follows that fixed proportions between z_2 and z_3 implies that $S_{13} = 0$ as well. Thus the first term in [25], $z_1(-S_{31}S_{22})$ will drop out, leaving the second and third terms,

$$t_3 = \kappa[-z_2(S_{11}S_{32})+z_3(S_{11}S_{22}). \qquad [26]$$

Substituting the identity $S_{22} = S_{23}(z_2/z_3)$ into [26] we now have

$$\begin{aligned} t_3 &= \kappa[-z_2(S_{11}S_{32})+z_3(S_{11}S_{23}(z_2/z_3))] \qquad [27] \\ &= \kappa[-z_2S_{11}S_{32}+ z_2S_{11}S_{23}] \\ &= 0 \end{aligned}$$

Thus we see that by assuming that the environmental good is consumed in fixed proportions with another market good, it follows that the optimal tax on the environmental good (above the Pigouvian price) is zero. This is because an additional tax on the “externality” of a “dirty good” would amount to taxing the same good twice. Indeed, the optimal revenue raising tax could be applied entirely to the dirty good, or entirely to the pollution permit since they are consumed in fixed proportions.

If we relax the fixed-proportions assumption, we can see that the optimal pollution tax will become positive. If even some degree of substitution between the dirty good and waste disposal is allowed, that means that $|S_{23}|$ will decrease, and the first term in [27], which is negative, will also decrease. This implies that the optimal revenue-raising tax will rise above zero, and the total tax will rise above the Pigouvian rate.

If, in addition to fixed proportions, one were to make the additional assumption that the dirty good is a closer substitute for leisure than the clean good, we could show that the optimal tax on the dirty good will be below the optimal tax on the clean good. If we collapse z_2 and z_3 into a single good z^*_2, we have the then have well-known result that the welfare cost will be minimized when

$$t_1 = \kappa[z_1 S_{22} - z^*_2 S_{12}]$$

$$t_2 = \kappa[z^*_2 S_{11} - z_1 S_{12}]$$

From this we can obtain, following Harberger (1964), the tax-price ratios ($\theta = t_i/p_i$) of the optimal taxes on the clean and dirty goods as

$$\frac{\theta_1}{\theta_2} = \frac{\varepsilon_{20} + \varepsilon_{21} + \varepsilon_{12}}{\varepsilon_{10} + \varepsilon_{21} + \varepsilon_{12}} \qquad [28]$$

where z_0 is leisure and where ε_{ij} is the compensated cross-elasticity $S_{ij}(p_j/z_i)$. The question is, will θ_2 be greater than zero? Obviously, when ε_{13} is smaller than ε_{23} then θ_2 will be less than θ_1, but that still requires that t_2 be greater than zero. If, as is likely, both z_1 and z_2 are substitutes for leisure, and their cross price elasticities with respect to leisure are low compared to the cross elasticities of demand between z_1 and z^*_2, then the ratio of θ_1/θ_2 will not be very different from unity (Harberger 1964). There are circumstances for which one or the other optimal taxes will be negative, however. If ε_{23} were greater than $\varepsilon_{21} + \varepsilon_{12}$, while at the same time ε_{13} is less than $\varepsilon_{21} + \varepsilon_{12}$, then θ_2 could be negative. But this result appears unlikely, and there is no reason to assume that it is true for the dirty good.

In contrast to the flexible model and neutral assumptions about substitutability developed here, the tax interaction hypothesis' rejection of the double dividend stems directly from the fixed-proportions assumption implicit in the caricatures of "dirty goods." These include polluting private goods (Sandmo 1975; Bovenberg and Mooij 1994), a dirty public good (Bovenberg and van der Ploeg 1994), a polluting resource used in production (Bovenberg and Goulder 1996), or as a fixed proportion of industrial output (Ligthart and van der Ploeg, 1994; Parry 1995).

Important consequences stemming from a seemingly benign assumption is not new. Indeed, there is precedent within the public finance literature for misleading conclusions being drawn when omitting goods from the utility function. For example, traditional models of optimal taxation held that unequal taxation across different goods could raise revenue with a zero welfare cost. Not until Little (1951) and others pointed out that leisure should be introduced as a separate good, was it recognized that this result did not hold. The current analysis suggests that a similar problem exists with regard to environmental taxation. By failing to recognize that environmental waste sinks are separate goods, and by omitting environmental waste disposal services from the utility function, optimal tax theory has overlooked the rationale for pricing and taxing them directly, and separately, from the taxes on other goods and services in the economy.

V. Conclusions

As with many resource allocation problems such as fisheries, pastures, or aquifers, pollution problems can be defined as market failures that arise in the absence of property rights for the services provided--the capacity to absorb and eliminate the residual byproducts of consumption and production. The introduction of a corrective Pigouvian tax on waste disposal both restores allocative efficiency and appropriates the rents from the use of these waste sinks, producing two social benefits when such a tax is introduced in a revenue neutral way. In addition, a revenue-raising tax should also be applied, raising the price of waste disposal above the Pigouvian rate, and producing yet a third benefit by broadening the tax base.

The confusing analyses and conflicting results in prior literature can be traced to the incompatibility between these two strands of theory, and especially on the Pigouvian approach which has sought to tax an "external effect" rather than the flow of a legitimate good or service. Indeed, the notion of an externality is an abstract metaphorical device that carries with it some misleading and unfortunate assumptions. Only when the goods and services provided by environmental assets are explicitly described and modeled, it is possible to integrate optimal revenue raising tax theory with optimal corrective taxation in a consistent manner. The conclusions of this analysis can be applied to a wide range of congestible public goods such as ocean fisheries, public highways, or the radio spectrum. Even in the absence of congestion costs, or when congestion costs are uncertain or unknown, taxation of environmental resources or other public goods should be part of an optimal revenue raising tax program because they broaden the tax base and appropriate the rents from exogenously supplied assets.

Environmental waste sinks provide essential services and represent ubiquitous and integral services in the economy. But their importance from a public finance perspective, and the unnecessarily high excess burden that results when not taxing them, has previously not been recognized or fully understood. For large categories of wastes and sinks such as atmospheric disposal of carbon gases, the inefficiencies that currently exist, and hence the potential social benefits of correcting them, may be large. Indeed, based on tax efficiency grounds alone (and neutral assumptions about tax interactions), an optimal global carbon tax has been estimated to reduce carbon emissions by 37 percent and produce $2.1 trillion in welfare benefits over the next 100 years (Jaeger, 1995).

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