On the Double Dividend of Environmental Taxation

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ABSTRACT

An income tax is equivalent to a uniform tax on all expenditures, including expenditures on commodity tax payments. This will compound the tax being applied to any taxed commodity. In the presence of an income tax, therefore, any expenditure tax (including a pollution tax) will produce a higher effective tax than its nominal tax rate would suggest. For example, a nominal Pigouvian tax applied to a polluting good will be equivalent to an effective tax higher than this.

These observations are used to shed light on recent debate surrounding the double dividend hypothesis. From this vantage point, the present analysis finds that the double dividend hypothesis is valid and that the optimal effective pollution tax is always the Pigouvian rate, although the presence of an income tax implies a correspondingly lower nominal pollution tax rate. The analysis also concludes that second-best optimal taxation implies a cleaner, not a dirtier, environment than for the first-best case, and that a higher marginal cost of public funds will raise the optimal tax on polluting goods and lower the optimal level of pollution.
The recent theoretical debate surrounding the “double dividend hypothesis” of environmental taxation suggests that the integration of optimal revenue-raising taxation with optimal corrective taxation is not adequately understood. The double dividend hypothesis refers to the idea that an equal-yield tax reform which introduces pollution taxes as substitutes for other revenue-raising taxes can improve environmental quality and reduce the overall cost of tax distortions. This hypothesis has been advanced by Tullock [26], Kneese and Bower [17], Terkla [25], Lee and Misiolek [18], and Oates [20], among others.

More recently the double dividend hypothesis has been rejected with the claim that, in a second-best world, “tax interactions” exacerbate the distortions from pollution taxes. In the most-cited of these papers, Lans Bovenberg and Ruud A. de Mooij [5] conclude that 1) “environmental taxes typically exacerbate, rather than alleviate, pre-existing tax distortions” even when introduced as part of an equal-yield tax reform; and 2) that “in the presence of pre-existing [revenue raising] taxes, the optimal pollution tax typically lies below the Pigouvian tax, which fully internalizes the marginal social damage from pollution.” They claim further that 3) “the marginal costs of environmental policy rise with the marginal cost of public funds,” and 4) that “the collective good of environmental quality directly competes with other collective goods”([5], p. 1085). These results have been interpreted as implying that Pigouvian principles must be modified ( [7], p. 985, 987). Additional contributions to this literature include Bovenberg and van der Ploeg [8], Parry [21], Goulder [14], Goulder, Parry, and Burtraw [15], Parry, Williams, and Goulder [22], and Fullerton [10]. These recent analyses have attracted considerable attention, in part because of their claim that the double dividend intuition is “wrong” ([6], p. 253) and that therefore analyses based on this notion is “flawed” ([10], p. 245).
The purpose of this paper is to suggest that the origins of the conflicting interpretations of
the double dividend hypothesis can be traced to the distinctions between nominal and effective
rates of taxation on goods and/or income. Whereas the nominal tax on a commodity (or source
of income) is the explicit tax rate being applied, it is well-understood from tax theory that an
income tax is equivalent to, or implicitly, a uniform expenditure tax. When taxes on both income
and expenditures are present, however, the effective tax on a commodity will not simply be the
sum of the nominal tax on the commodity and the implicit tax corresponding to the income tax.
Rather, because the income tax is equivalent to a uniform tax on all expenditures, it is also an
implicit tax on the commodity tax payments, since tax payments represent an expenditure and
are thus also subject to this implicit tax. Therefore, any commodity tax, including pollution
taxes, will be equivalent to higher effective taxes than their nominal tax rates would suggest.

This paper also examines Sandmo’s well-known optimal tax formula in the context of the
tax interaction claim. On inspection this formula may appear to confirm the tax interaction claim
when it is seen as having two separate components, one related to the optimal revenue-raising
tax, and the second involving the optimal pollution-tax. The two components of the tax formula
cannot, however, be evaluated independently because of the simultaneous determination of the
tax-inclusive price in the equation.

The analysis finds that when taxes on goods are evaluated according to their effective
rates, that neither Ramsey formulas nor Pigouvian principles need fundamental alteration in the
context of environmental taxation, and that the double dividend hypothesis is valid. The present
analysis concludes that in a second-best world where government uses income taxes to raise
revenue: a) taxing pollution will typically alleviate pre-existing tax distortions, b) the optimal
effective pollution tax will always equal the Pigouvian rate, c) providing a clean environment is a
complement to, not a competitor with, the provision of other collective goods, and d) the marginal costs of environmental policy will fall rather than rise with a rise in the marginal cost of public funds. However, as with any expenditure tax in the presence of an income tax, the nominal tax rate necessary to achieve any desired effective tax will be lower than the desired tax.

The remainder of the paper is organized as follows. Section I distinguishes between nominal and effective tax rates and reinterprets the model of Bovenberg and de Mooij; section II examines Sandmo’s optimal tax formula, while section III approaches these issues from the perspective of the marginal cost of public funds. In section IV the double dividend hypothesis is evaluated directly by identifying the welfare effects of environmental tax reform, and section IV proposes an intuitive explanation for the existence of the double dividend. Summary conclusions are presented in section V.

I. Nominal, implicit, and effective tax rates in the context of pollution taxation

The distinction between the nominal and effective tax rates can be identified in a model with one commodity X and only labor income, L. Assume prices and wages equal unity and that there is a labor tax $t_L$. The expenditure constraint can be written as

$$X = (1-t_L)L. \tag{1}$$

The labor tax can understood to be equivalent to, or implicitly, an expenditure tax on X by writing this as

$$\left(\frac{1}{1-t_L}\right)X = L. \tag{2}$$

For purposes of evaluating incentives, allocations, or welfare changes, there is no difference between this implicit, effective tax on X and an explicit commodity tax of an equal magnitude.
It may be less obvious, however, that when an expenditure tax $t_X$ is introduced in the presence of an income tax $t_L$, that the effective tax on $X$ will rise by more than $t_X$, and that the effective tax on $X$ will thus be higher than the sum of the two taxes (the implicit tax and the nominal tax). This can be seen clearly by first writing the expenditure relation with the introduced expenditure tax $t_X$ as

$$(1 + t_X)X = (1 - t_L)L.$$  \hfill (3)

By rearranging the labor tax as an implicit expenditure tax, the relation becomes

$$\left(\frac{1}{(1-t_L)} + \frac{t_X}{(1-t_L)}\right)X = L$$  \hfill (4)

By comparing this result with (2), we see that the first term in brackets in (4) is identical to the implicit tax in (2), which is the implicit, tax-equivalent to the labor tax. The second term in brackets in (4), however, is greater than the nominal expenditure tax $t_X$ since the denominator of that term is less than one. Thus, the introduction of a tax $t_X$ has raised the effective tax on that commodity by more than $t_X$. The two taxes are directly compounding each other in a straightforward, algebraically identifiable way. Intuitively, in order to pay the commodity tax an individual must pay it out of income which is also taxed, so that there is a “tax on the tax.” In the terminology being employed here, there is an implicit labor tax compounding the nominal commodity tax, giving rise to a higher effective commodity tax than the nominal commodity tax rate would suggest. Once again, for purposes of evaluating incentives, allocations, or welfare consequences, it is this effective tax on a given commodity that corresponds to the real variables of interest to economists.  

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1 To see this clearly, assume a labor tax of 20 percent and a price for $X = 1$. We can interpret the labor tax as a tax on each commodity equal to 25 percent since $1 + 0.25 = 1/(1-0.2)$. Each time the commodity is purchase for $1$, we know that $1.25$ of earned income was required in order to both purchase the good and pay the $0.25$ income tax on the $1.25$ of income. A unit of the good costs $1.25$ worth of leisure. If
The importance of this distinction for evaluating the double dividend hypothesis can be seen by reexamining the model and analysis of Bovenberg and de Mooij [5]. They consider a simple economy where linear technologies produce “clean” and “dirty” commodities and where leisure can be consumed directly or supplied as labor which is the only input into production. They assume that there is a dirty good which “has an externality,” and that government has a revenue requirement to provide public consumption. Household utility is derived from consumption of leisure (L), clean (C) and dirty (D) commodities, public consumption (G), and the amenity benefits (E) of environmental quality (clean air, water, etc.). They assume that consumption of the “dirty good” adversely affects environmental quality such that \( E = e(ND) \); \( de/d(ND) < 0 \), where \( N \) is the number of households. They also assume that all markets are competitive, and that the utility function is homothetic.

Under these assumptions, existing literature tells us that the optimal revenue-motivated tax program will involve uniform taxes on each commodity (see Atkinson and Stiglitz [1]). Since Bovenberg and de Mooij take the clean good to be the numeraire and employ a labor tax, it follows that the optimal revenue-motivated tax on the dirty good will be zero as well. Thus we can employ a labor tax as an instrument to achieve optimal revenue-motivated taxation (see Auerbach [2]), since, as above, the labor tax will be equivalent to uniform commodity taxes whether labor income is multiplied by \( (1-t_L) \) or whether all expenditures are multiplied by \( (1+t) \) so long as \( (1+t) = 1/(1-t_L) \).

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we now introduce a $1.00 commodity tax on the good, we might be tempted to conclude that the tax on the good has been raised by $1.00. However, this nominal tax understates the correct measure of the effective tax. In order to pay the $1.00 commodity tax, an individual must earn $1.25, and pay $0.25 in additional income taxes, in order to have $1.00 left to pay the commodity tax. Thus the effective tax on the good has been raised by $1.25, not $1.00: a unit of the good costs an additional $1.25 in terms of leisure.
For the Bovenberg and de Mooij model, we can designate the nominal pollution tax as $t_D$ and the effective pollution tax as $\tau_D$. These two taxes will be equal in the absence of any labor tax, as will their optimal values $t^*_D = \tau^*_D$. However, in the presence of a labor tax, the optimal effective tax on the externality will equal the marginal external cost, or the Pigouvian tax $\tau^*$, only if the nominal corrective tax is set so that $t_D = \tau^*_D(1-t_L)$. Bovenberg and de Mooij instead set the nominal corrective tax on the dirty good equal to the Pigouvian rate $t^*_D$. From their household budget constraint (p. 1086) we have

$$C + (1 + t^*_D)D = h(1-t_L)(1-L) \quad (5)$$

where $h$ is population. Similar to the derivation above, we can divide through by $(1-t_L)$ to produce the effective tax rates on each commodity where

$$\frac{1}{(1-t_L)}C + \frac{(1 + t^*_D)}{(1-t_L)}D = h(1-L).$$

Rewriting this as

$$\frac{1}{(1-t_L)}C + \left[\frac{1}{(1-t_L)} + \frac{t^*_D}{(1-t_L)}\right]D = h(1-L) \quad (6)$$

we can see that the difference between the effective tax rates on the two goods is equal to the second term in brackets since the first term is identical to the effective tax on the clean good. That term, $\frac{t^*_D}{(1-t_L)}$, is higher than $t^*_D$. Although Bovenberg and de Mooij have introduced a *nominal* pollution tax equal to the Pigouvian level, the *effective* tax on the polluting good has been raised higher than the Pigouvian rate.

From this starting point, Bovenberg and de Mooij examine the welfare effects of a small reduction in the pollution tax on $D$. From their equation (5), where the welfare impact is described as
\[
\frac{dU}{\lambda} = h t_L dL + \left[ t_D - N \frac{\partial u}{\partial E} \left( -\frac{de}{d(ND)} \right) \right] dD, \tag{7}
\]

they conclude correctly that welfare would increase if the tax \( t_D \) on the dirty good were lowered below the Pigouvian rate \( t_D^* \) because a) the first term on the right-hand side of (7) is positive (since a lower tax \( t_D \) will raise the real wage and assuming that labor supply is upward sloping), and b) the second term on the right-hand side will be zero when \( t_D = t_D^* \) since

\[
t^*_D = N \frac{\partial u}{\partial E} \left( -\frac{de}{d(ND)} \right) \frac{1}{\lambda}. \tag{8}
\]

Their interpretation certainly holds for the nominal tax rate they have introduced. However, welfare is improving because the marginal reduction in the effective pollution tax represents a movement toward the Pigouvian rate, not away from it. The distortionary effects of the tax appear large, and the tax base appears to have been narrowed excessively, precisely because the cost of the dirty good in terms of leisure has been raised by more than the Pigouvian tax.

If, instead of setting the initial nominal tax rate equal to the Pigouvian rate, Bovenberg and de Mooij had set it such that the effective tax rate was the Pigouvian rate, \( t_D = \tau^*_{D}(1-t_L) \), then their relation (5) would be

\[
\frac{dU}{\lambda} = h t_L dL + \left[ \tau^*_D (1-t_L) - N \frac{\partial u}{\partial E} \left( -\frac{de}{d(ND)} \right) \right] dD. \tag{9}
\]

With the pollution tax introduced in this way, we can see that the second term on the right-hand side is negative since \( \tau^*_D (1-t_L) < \tau^*_D \). As a result of this, the sign of the welfare change for a reduction in \( t_D \) below \( t_D^* \) is ambiguous. Thus, in terms of the effective tax applied to the polluting good, the claim that the optimal pollution tax will be below the Pigouvian tax cannot be substantiated.
Fullerton [10] has suggested that Bovenberg and de Mooij’s results are correct but that their choice of numeraire may lead to misinterpretation, noting the well-established equivalence of alternative numeraires for achieving optimal revenue-motivated taxation from optimal tax theory. The choice of numeraire is clearly relevant to the issue being developed here since a change in numeraire will often represent a shift from (to) a world with taxes on both expenditures and income to (from) one with taxes only on expenditures. But the essential distinction between the nominal and effective tax is independent of optimal taxation or the choice of numeraire. Indeed, the distinction between the nominal and effective tax rate has been introduced above without reference to the environment, optimal taxation, or the choice of numeraire. The key point is the compounding effect on tax rates when both income and expenditures are taxed, and this occurs whenever both income and expenditures are taxed.

This point is also symmetrical: expenditure taxes can be viewed as implicit taxes on income, or income taxes can be seen as implicit taxes on expenditures. From the reverse perspective we can see that the effective labor tax will be higher than the nominal labor tax in the presence of expenditure taxes. Indeed, in support of the tax interaction claim it has been pointed out that a pollution tax acts to (effectively) lower the real wage, and thus encourages consumption of leisure (for example, see Parry 1995, Bovenberg and de Mooij 1994). An equally-important, symmetrical observation is that the effective pollution tax is higher than the nominal tax rate these authors have introduced. It is important to recognize not only that the pollution tax compounds the labor tax, but that the labor tax compounds the pollution tax, and that these “compounded” taxes, or effective taxes, are the real variables deserving our attention. What Bovenberg and de Mooij and others have done is to introduce a given pollution tax only to detect a higher-than-expected distortion. The interpretation suggested here is that these authors
have detected a higher-than-expected distortion because they have introduced a higher-than-expected tax.

In an analysis drawing conclusions similar to Bovenberg and de Mooij, Parry suggests how these results may be interpreted for environmental subsidies on “clean goods.” Based on his conclusion that “the gains from using pollution tax revenues to substitute for labor tax revenues tend to be more than offset by the cost of exacerbating the preexisting distortion in the labor market” ([21] p. S-76), he extrapolates that a subsidy will increase the demand for labor due to its “interdependency effect,” which will reduce the cost of financing the subsidies. He concludes that “economists may have been overly pessimistic about the costs of subsidies for environmentally cleaner goods, such as public transportation” ([21] p. S-76).

Here again the distinction between nominal and effective tax (or subsidy) rates is essential. By subsidizing consumption of a good in the presence of a labor tax, the magnitude of the effective subsidy is raised (or the effective tax on the good is lowered) by a larger amount than the nominal subsidy would suggest. This can be seen using Bovenberg and de Mooij’s notation but for a subsidy $s_C$ on the clean good so that we have

$$\left[\frac{1}{(1-t_L)} + \frac{s_C}{(1-t_L)}\right] C + \frac{1}{(1-t_L)} D = h(1-L).$$

The second term in brackets is the effective subsidy on clean consumption and will be larger than the nominal subsidy. The effects of this subsidy on labor supply, labor tax revenue, and welfare changes will be correspondingly higher. Intuitively, the consumer is avoiding paying not only a portion of the cost of the clean good, but also the labor tax that would have corresponded to the income necessary to pay for that same portion of the commodity price (that would have been paid in the absence of the subsidy). Parry’s “interdependency effect” can be seen as alluding indirectly and incompletely to the divergence between the nominal and effective tax (or subsidy).
II. Interpretation of Sandmo’s optimal tax rule

Sandmo’s [24] well-known optimal tax formula for integrating revenue-motivated and pollution taxes may appear to confirm the tax interaction claim that rejects the double dividend hypothesis, as suggested by Fullerton [10], Bovenberg and de Mooij [5], and Bovenberg [4]. Sandmo’s optimal tax rule can be represented as

\[
\theta = \left(1 - \frac{1}{\mu}\right)R + \frac{1}{\mu} \tau^* 
\]

where \(\theta\) is the optimal tax rate (where \(\theta = t/p\)), \(R\) is the Ramsey term composed of own- and cross-price effects, \(\mu\) is the marginal cost of public funds, and \(\tau^*\) is the optimal pollution tax (where \(\tau^* = MED/p\) when MED is the marginal environmental damage). For a non-polluting good we can simply assume that the second term goes to zero. Therefore it would appear as though the difference in the optimal tax on a non-polluting versus a polluting good will equal the second term. Fullerton [10] and Bovenberg [4] point out that the second term is less than \(\tau^*\) since \(\mu\) is assumed to be greater than one, so that the tax differential (the difference between the optimal tax on a polluting and a nonpolluting good) is less than the marginal social damage, or that the environmental component is less than the Pigouvian rate.

Sandmo’s result should be interpreted cautiously, however, because it involves two simultaneous equations. Both \(\theta\) and \(\tau\) are ratios of the price, \(p\), which is endogenous to the optimal tax, since \(p = p^0 + t\) where \(p^0\) is the before-tax price. Rewriting Sandmo’s optimal tax rule by replacing \(\theta\) with \(t/p\) and \(\tau\) with \(MED/p\), we can write

\[
\frac{t}{p} = \left(1 - \frac{1}{\mu}\right)R + \frac{1}{\mu} \frac{MED}{p}. \tag{10}
\]
Since \( p \) will rise with increased \( t \), the introduction of a non-zero second term may cause \( t \) to rise by more than MED even though the second term on the right side is less than MED/p.

To see this clearly we can make the simplifying assumption (as does Sandmo) that the cross-price effects for all goods are zero, so that we can write the \( R \) term as \(-1/\eta\) where \( \eta \) is the own-price elasticity of demand. Now multiply through by \( p \) to get:

\[
t = \left(1 - \frac{1}{\mu}\right) \frac{-1}{\eta} p + \frac{1}{\mu} \text{MED}
\]  

(11)

Consider a numerical example involving two similar goods, one clean and one polluting, produced at constant cost so that \( P^0 = 1 \) for both. For the polluting good assume MED is constant at .20, and that the own price elasticities for both goods, \( \eta_{DD} \) and \( \eta_{CC} \), equal -1. If the tax base is large relative to the potential revenues from either of these goods, then we can assume that the marginal cost of public funds, \( \mu = 1.25 \), is constant.

For the clean good we can use (11) above, omit the second term, and combine it with the identity \( P_C = P^0 + t^*_C \) to estimate the optimal tax as

\[
t_c = \left(1 - \frac{1}{1.25}\right) \frac{-1}{\eta} P_C
\]

or

\[
t_c^* = \left(1 - \frac{1}{1.25}\right) \frac{-1}{-1} (1 + t_c^*) = 0.2 \cdot (1 + t_c^*) = 0.20 + 0.2t_c^*
\]

\[
0.8t_c^* = .20
\]

\[
t_c^* = 0.20 / 0.8 = 0.25
\]

For the dirty good we can similarly estimate the optimal tax using (11) to get

\[
t_d = \left(1 - \frac{1}{1.25}\right) \frac{-1}{-1} (1 + t_d) + \frac{20}{1.25} = 0.2(1 + t_d) + .16 = .20 + 0.2t_d + .16
\]
\[0.8t_D = 0.36\]

\[t_D = \frac{0.36}{0.8} = 0.45\]

From this we can see that the tax differential equals MED or, \(t_D - t_c = 0.45 - 0.25 = 0.20\). Thus, we cannot conclude by inspection that Sandmo’s result supports the tax interaction claim or that the "tax differential" will be lower than the Pigouvian rate. \(^2\)

A more general result for the optimal pollution tax can be found if we use (10) and subtract the expression for the optimal tax on the clean good from the expression for the optimal tax on the dirty good and evaluate this difference. With before-tax prices of D and C equal to one, we have the identities \(P_D = P_D^0 + t_D = 1 + t_D\) and \(P_C = P_C^0 + t_C = 1 + t_C\). Thus, we can write the optimal tax on the clean good as

\[t_c = \left(1 - \frac{1}{\mu}\right)(1 + t_c)R\]  \hspace{1cm} (12)

and the optimal tax on the dirty good as

\[t_D = \left(1 - \frac{1}{\mu}\right)(1 + t_D)R + \frac{1}{\mu}MED\]  \hspace{1cm} (13)

where \(R\) is the Ramsey term. We want to evaluate the difference between these two optimal taxes, or

\[t_D - t_C = \left(1 - \frac{1}{\mu}\right)(1 + t_D)R - \frac{1}{\mu}MED - \left(1 - \frac{1}{\mu}\right)(1 + t_C)R\]  \hspace{1cm} (14)

\(^2\) This particular result is not entirely inconsistent with some claims made under strong restrictions on preferences (L. Goulder, personal communications, Feb. 27, 1998), since the elasticity and cross-price assumptions made in this example imply that the labor supply is perfectly inelastic. By contrast, if we assume all of the following: that a) labor supply is upward sloping, b) all cross-price effects are zero, and c) the polluting good is an average substitute for leisure, then the tax differential will indeed be less than the Pigouvian rate. This, however, is an example involving strong restrictions on preferences, and more importantly it will produce much more modest divergences in the effective tax differential than has been suggested (in terms of nominal tax differentials) in the literature.
which can be written as

\[ t_D - t_C = \left(1 - \frac{1}{\mu}\right) (t_C - t_D) R - \frac{MED}{\mu} \]

or

\[ \frac{(t_D - t_C)}{(t_C - t_D)} = \left(1 - \frac{1}{\mu}\right) R - \frac{1}{\mu} \frac{MED}{(t_C - t_D)} = -1 \]

Rearranging terms we can write this as

\[ -1 - R + \frac{R}{\mu} = -\frac{1}{\mu} \frac{MED}{(t_C - t_D)} \]

and the tax differential can now be isolated to give

\[ t_D - t_C = \frac{MED}{\left(R - \frac{\mu - \mu R}{\eta}\right)} \]  \hspace{1cm} (15)

We can see that if the Ramsey term \( R \) equals 1, then the denominator on the right-hand side becomes \( 1 - \mu + \mu = 1 \), and the optimal tax on the dirty good will exceed the tax on the clean good by MED. If \( R < 1 \), the optimal tax differential will be greater than MED, and if \( R > 1 \), the tax differential will be less than MED.  

Whether the tax differential will be less than, or more than, the marginal environmental damage is an empirical question dependent on the value of the Ramsey term in (10). A priori, there is no reason to believe that the Ramsey term will be greater than or less than one. In a world with many goods, where the Ramsey term for nonpolluting goods will differ from that of a given polluting good, there is an infinite set of possibilities for the value of the optimal tax.

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3 Returning to the Bovenberg and de Mooij relation, if we assume that the Ramsey terms equal one so that the optimal tax differential will equal the Pigouvian rate, we can set the left side of (9) equal to zero. The relation can then be rearranged to give us \( dL/dD = \tau*/h \), indicating intuitively that the optimal tax will
differential, but no theoretical reason to presume that it is less than or more than the Pigouvian rate.

Numerical estimations of the effect of tax interactions on optimal pollution taxes include the general equilibrium models of Bovenberg and Goulder [7]. They estimate that with marginal environmental damages of $75, and a MCPF of 1.252, that the optimal pollution tax is $60 ([7], Table 3, p. 994). On the basis of these and other results, they conclude that “the presence of distortionary taxes requires a modification of the Pigouvian principle” ([7] p. 987) and that “optimal environmental tax rates are generally below the rates suggested by the Pigouvian principle” ([7] p. 994). While this is expected for the nominal pollution tax, the effective tax will be higher. Although they do not report the labor tax rates for each estimation, if we assume the Ramsey terms equal one we can use Sandmo’s optimal tax result to show that a MCPF of 1.252 implies a labor tax of 0.20, or equivalently a tax on all expenditures of 0.25. Since this implicit tax will be applied to expenditures on the pollution tax itself, we can calculate the effective pollution tax corresponding to their optimal nominal tax as $(1.25) \times $60 = 75, which is precisely the marginal environmental damage they have assumed, or the Pigouvian rate. They are correct in concluding that optimal nominal pollution tax will be lower than the Pigouvian rate, but not in repealing Pigouvian principles corresponding to the effective tax rates.

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4 In other simulations they get lower results for what are referred to as “optimal” pollution taxes—but these are not “optimal” since they have substituted pollution taxes for the least distorting of the preexisting taxes in their model (labor) rather than the most distorting preexisting taxes (capital) ([7] pp. 992-993).
III. The marginal cost of public funds in the presence of corrective taxes

Since both tax components—revenue-motivated and corrective—serve dual purposes (of raising revenue and discouraging pollution), resolving the issue of which component of the total optimal tax is larger or smaller than expected is not important beyond the need, in the context of the tax interaction claims, for theoretical clarification. The analysis here suggests that it is the Ramsey term, and hence the revenue-motivated tax, that may vary, but that the optimal pollution tax will not. A more important question involves the implications for the environment: What happens to the optimal level of pollution when corrective and revenue-motivated taxes interact; should it be cleaner or dirtier than the Pigouvian tradition would suggest?

Proponents of the tax interaction analysis find that “the collective good of environmental quality directly competes with other collective goods” ([6] p. 1085), and that “an increase in government revenue requirement means an increase in the distortionary effects of taxes, a higher [\( \mu \)], more weight on the revenue-raising term, and less weight on the marginal environmental damage”([10] p. 248). The analysis here concurs that as an income tax is raised to provide more public funds, the optimal (nominal) pollution tax will decline. However, the effective tax on pollution will necessarily rise. The intuition for this can be shown by introducing the notion of the marginal cost of public funds.

Assume initially that we have a corrective tax \( t^P \) (using the superscript \( P \) to indicate the pollution tax and superscript \( R \) for the revenue-motivated tax) on the dirty good, which is set equal to the optimal, or Pigouvian, rate \( t^P* \), and that the revenue collected \( R^{P*} \) is returned lump-sum to the economy. This is precisely the first-best starting point taken by Ramsey in acknowledgement of the problem posed to him by Pigou: “…I shall suppose that, in Professor Pigou’s terminology, private and social net products are always equal or have been made so by
State interference…” ([23] p. 47). From this starting point, the provision of public goods can be funded without distortion to the economy so long as the required revenue $R$ is less than or equal to $R^p*$.

But what happens when the required revenues exceed $R^p*$ so that additional taxes are necessary? If the clean and dirty goods are similar in all other relevant respects, and if we assume a homothetic utility function, then it would be tempting to conclude that equal revenue-motivated taxes on both the clean and the dirty good will be optimal. However, with a pre-existing corrective tax, the optimal revenue-motivated taxes on the two goods will differ, precisely because they have differing marginal costs of public funds. The marginal cost of public funds (MCPF) for a good $X$ is defined as

$$\text{MCPF}_X = \frac{X dt}{X dt + t \frac{dX}{dt} dt} = \frac{X}{X + t \frac{dX}{dt}}$$  \hspace{1cm} (16)$$

With the numerator being the cost imposed on the private economy and the denominator being the change in revenue resulting from an incremental tax $dt$. In the case of the clean good, the marginal cost of public funds for an initial revenue-motivated tax $\Delta t$ will be

$$\text{MCPF}_C = \frac{C}{C + \Delta t \frac{dC}{dt}} \equiv \frac{C}{C}$$  \hspace{1cm} (17)$$

and will be approximately equal to 1 for an arbitrarily small $\Delta t$. However, in the case of the dirty good, where the corrective tax $t^p*$ is already in place, the marginal cost of public funds for the same incremental revenue-motivated tax $\Delta t$ will be

$$\text{MCPF}_D = \frac{D}{D + (t^p* + \Delta t) \frac{dD}{dt}} > 1$$  \hspace{1cm} (18)$$
Since the second term in the denominator will be positive ($t^p > 0$), we can see that the $\text{MCPF}_D$ will exceed one.

This difference is illustrated in figure 1 where the $\text{MCPF}$ for both goods is equal to the ratio of the shaded area divided by the difference between the shaded area and the diagonally striped area. For small initial revenue-motivated taxes on both goods, the numerators of each good’s $\text{MCPF}$ measures are equal ($D = C$), but the denominators will differ because in the case of the polluting good the striped area is large and thus the $\text{MCPF}_D$ will be higher. Because government is already collecting revenue tied to the consumption of the polluting good, and because the introduction of a revenue-motivated tax discourages consumption of the good, the revenue-motivated tax will cause a reduction in the revenue collected from the corrective component of the tax. Thinking of these two components of the tax on the polluting good as separate sources of revenue, we can see that the introduction of a revenue-motivated tax on the polluting good not only imposes a cost on the private economy, but it also imposes a cost on government itself; additional revenue from the revenue-motivated tax comes at the expense of a reduction in the initial source of revenue, the corrective tax. This loss of revenue from the corrective tax is partially offset, however, by the additional improvements in environmental quality.

How does this analysis enter into our assessment of optimal taxation? We understand that the well-known Ramsey formulas for optimal tax rates serve to equalize the marginal cost of public funds across commodities in order to minimize the total cost of raising revenue. To the extent that raising revenue inadvertently raises welfare by internalizing external costs, we should take this into account as well, and thus seek to equalize the “net” marginal cost of public funds, where any environmental benefit of reducing pollution (per dollar of revenue collected) is
included. Therefore, for a world with a clean good \( C \) and a polluting good \( D \), we would want to equate

\[
\text{MCPF}_C = \text{MCPF}_D - \text{MEBPF}_D \tag{19}
\]

where MEBPF is the marginal environmental benefit per dollar of revenue collected from taxing the polluting good. Assuming that the cross-price effect between the two goods is zero, we can write this relation explicitly as

\[
\frac{\lambda C}{C + t_C \frac{dC}{dP_C}} = \frac{\lambda D}{D + t_D \frac{dD}{dP_D}} - \frac{N \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}}{D + t_D \frac{dD}{dP_D}} \tag{20}
\]

where again environmental quality \( E = e(ND) \) and \( N \) is the number of households, and where \( \lambda \) is the marginal utility of income. If we take the marginal cost of public funds associated with taxing the clean good as a reference against which to judge MCPF\(_D\) we can substitute the notation \( \mu = \text{MCPF}_C \) and write the above formula as

\[
\mu = \frac{\lambda D}{D + t_D \frac{dD}{dP_D}} - \frac{N \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}}{D + t_D \frac{dD}{dP_D}} \]

which can be rearranged as

\[
D + t_D \frac{dD}{dP_D} = \frac{\lambda D}{\mu} - \frac{N \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}}{\mu}.
\]

Subtracting \( D \) from both sides and dividing through by \( dD/dP_D \) gives us

\[
t_D = -\frac{D}{dP_D} \frac{dD}{dP_D} + \frac{\lambda D}{\mu} \frac{dD}{dP_D} - \frac{N \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}}{\mu}.
\]

Collecting terms and dividing through by \( P_D \) produces
\[
\frac{t_d}{p_d} = \left(1 - \frac{\lambda}{\mu} \right) \frac{-1}{\frac{dD}{dP_d} \frac{P_d}{D}} - \frac{N}{p_d \mu} \frac{\partial U}{\partial E} \frac{de}{dD}.
\] (21)

We can substitute the efficiency condition \( p_d \lambda = \frac{\partial U}{\partial D} \) and \( \phi = \lambda/\mu \) to write the relation as

\[
\frac{t_d}{p_d} = \left(1 - \phi \right) \frac{-1}{\eta_{DD}} - \phi N \frac{\partial U}{\partial U} \frac{de}{dD}.
\] (22)

where \( \eta_{DD} \) is the own price elasticity of demand. We can see that this is the same as Sandmo's result ([24] p. 93) discussed above, confirming that the optimal tax rate on a polluting good will be that rate which equalizes the marginal cost of public funds across commodities, net of the environmental benefits of introducing the tax.

Do revenue raising goals conflict with environmental goals? These results suggest that public finance goals and environmental goals are complementary. Environmental taxes do not become more distorting as government revenue requirements increase. Rather, as the revenue requirement rises above \( R^{P*} \), the optimal tax on both goods will rise, consumption will decline, and so will the level of pollution. Thus, the higher the revenue requirements of government, the cleaner will be the environment under optimal taxation: a result suggesting that the collective good of environmental quality is a complement to, not a competitor with, the provision of other collective goods.

Although these conclusions differ with the interpretations made by Bovenberg and de Mooij [5], Bovenberg and van der Ploeg [8], Bovenberg and Goulder [7], Fullerton [10], Parry [21], and others, it is important to recognize that for any proposed tax change, the starting point matters greatly. General conclusions about optimal taxation are difficult to apply to a situation with preexisting taxes, in part because the first-best, or untaxed, situation is not observable. In a
second-best world where existing income taxes already act as implicit taxes on polluting goods, the levels of pollution will already be lower than they would be in the absence of any taxes. Thus, the observed level of pollution and marginal environmental damages will differ from the theoretical first-best starting point, the reference point from which we would normally evaluate the optimal pollution tax. From the observed starting point, therefore, the additional pollution tax justified to correct the externality will be lower than that which would be justified from a first-best starting point. Moreover, given preexisting income taxes, the nominal tax required to achieve the optimal pollution tax will also be correspondingly lower than the Pigouvian rate. It remains true, however, that relative to an untaxed world, the higher the cost of public funds the lower will be the optimal level of pollution.

III. Welfare effects of environmental tax reform

We now turn directly to the “double dividend” hypothesis, which refers to whether there are two distinct welfare benefits from an equal-yield tax reform that substitutes pollution taxes for other revenue-raising taxes. For a simple economy like the one described above we can write the individual utility function to be maximized as \( U(C, D, E, L) \) where the arguments are the clean good, the polluting good, the environmental amenity, and leisure, respectively. Income is assumed to be a function of labor supply and the constant wage, so that \( Y = w(1-L) \). The indirect utility function can thus be defined as \( V(U(C(P,Y), D(P,Y), E(hD), L(P,Y))) \). Leaving leisure as the untaxed good, but where \( P_D = P_D^0 + t_D \) and \( P_C = P_C^0 + t_C \), the optimal tax problem can be characterized as

\[
\operatorname{MAX}_p V(P_C, P_D, E, w) \text{ subject to } (t_D D + t_C C = R). \tag{23}
\]

so that the Lagrangian constrained optimization problem becomes
\[ V(P_C, P_D, E, w) - \mu(R - t_D D + t_C C), \]

where in the case of the unpriced environmental good we define \( \partial V/\partial E = \partial U/\partial E \). When we assume that the cross-price effects are zero between the two goods, the first-order conditions with respect to each price are

\[
\frac{\partial V}{\partial P_D} = -\lambda D + \mu \left[ t_D \frac{\partial D}{\partial P_D} + D \right] + h \frac{\partial U}{\partial E} \frac{\partial D}{\partial D \frac{\partial P_D}{}} \tag{24}
\]

and

\[
\frac{\partial V}{\partial P_C} = -\lambda C + \mu \left[ t_C \frac{\partial C}{\partial P_C} + C \right]. \tag{25}
\]

From a starting point with equal revenue raising taxes on both goods \( (t_D^0 = t_C^0 < t_P^*) \), we want to assess the welfare effects of an equal yield tax shift which will raise the corrective tax on the polluting good up to the Pigouvian level \( t_P^* \). With the welfare effects of an increase in the tax (price) of each good given by (24) and (25), the welfare change per dollar of revenue can be written as

\[
\frac{dR}{dP_D} \frac{dP_D}{dR} \frac{dV}{dP_D} \frac{dP_D}{dR} \frac{dV}{dP_C} \frac{dP_C}{dR}.
\]

Defining \( \tilde{W} \) as the welfare effect of a revenue-neutral tax shift toward the polluting good (with offsetting revenue changes in taxation of the clean good), we can write

\[
\frac{d\tilde{W}}{dR_P} = \frac{dV}{dP_D} \frac{dP_D}{dR} - \frac{dV}{dP_C} \frac{dP_C}{dR} \tag{26}
\]

or alternatively as

\[
\frac{d\tilde{W}}{dP_D} = \frac{d\tilde{W}}{dR} \frac{dR}{dP_D} = \frac{dV}{dP_D} - \frac{\partial V}{\partial P_D} \frac{dR}{dP_C}.
\]

Substituting (20) and (21) and writing \( dR/dP_D \) and \( dR/dP_C \) explicitly, we have
\[
\frac{d \tilde{W}}{dP_D} = -\lambda D + \mu \left[ t_D \frac{\partial D}{\partial p_D} + D \right] + h \frac{\partial U}{\partial E} dD \frac{\partial D}{\partial p_D} - \left[ -\lambda C + \mu \left( t_S \frac{\partial C}{\partial p_S} + C \right) \right] \left( \frac{\partial D}{\partial p_D} + D \right) \left( \frac{\partial C}{\partial p_C} + C \right)
\]

which can be simplified as

\[
\frac{d \tilde{W}}{dP_D} = -\lambda D + \lambda C \left( t_D \frac{\partial D}{\partial p_D} + D \right) - MED \frac{\partial D}{\partial p_D}
\]

and further as

\[
\frac{d \tilde{W}}{dP_D} = -\lambda D + \mu_c \left( t_D \frac{\partial D}{\partial p_D} + D \right) - MED \frac{\partial D}{\partial p_D}. \tag{27}
\]

Rearranging this and assuming \( \lambda = 1 \) we can write

\[
\frac{d \tilde{W}}{dP_D} = (\mu_c - 1)D + \mu_c t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D}
\]

or as

\[
\frac{d \tilde{W}}{dP_D} = (\mu_c - 1)D + (\mu_c - 1 + 1)t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D}
\]

which in turn can be written as

\[
\frac{d \tilde{W}}{dP_D} = (\mu_c - 1)D + \mu_c t_D \frac{\partial D}{\partial p_D} - t_D \frac{\partial D}{\partial p_D} + t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D}. \tag{28}
\]

Collecting terms this can be written as

\[
\frac{d \tilde{W}}{dP_D} = (\mu_c - 1) \left( D + t_D \frac{\partial D}{\partial p_D} \right) + \left[ t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D} \right]. \tag{29}
\]

We can see here that the combination of the last two terms in brackets is just the Pigouvian benefit. In addition, however, so long as \( \mu \) is greater than 1 and the second parenthetic term is
positive \((\partial R_D/\partial P_D > 0)\), the first term will be positive, representing the second benefit from the equal-yield tax shift. Thus, the welfare gain from raising \(t_D^0\) to \(t_D^P\) will be

\[
\tilde{W}(t^P) = \int_{t_D^0}^{t_D^p} (\mu_c - 1) \left( D + t_D \frac{\partial D}{\partial p_D} \right) + \int_{t_D^0}^{t_D^p} \left[ t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D} \right]
\]  

(30)

As long as \(t_D^0 < t_D^P\), the welfare effects for this tax reform will exceed the traditional Pigouvian benefits. Once the Pigouvian tax has been reached, the second term in (29) will equal zero, and become negative, but it will still be desirable to raise the tax on the polluting good above the Pigouvian tax, until the first term and second terms are exactly offsetting. The welfare effects of the optimal equal-yield tax reform will correspond to raising the tax on the polluting good to \(t^{**}\), or until marginal changes in the first and second terms of (29) are offsetting or

\[
\tilde{W}(t^{**}) = \int_{t_D^0}^{t^{**}} (\mu_c - 1) \left( D + t_D \frac{\partial D}{\partial p_D} \right) + \int_{t_D^0}^{t^{**}} \left[ t_D \frac{\partial D}{\partial p_D} - MED \frac{\partial D}{\partial p_D} \right]
\]  

(31)

If the initial tax on the polluting good is equal to or above the Pigouvian tax, then there will still be a welfare gain to raise the tax to the optimal level, but there will not be a "double dividend."
The optimal tax will occur when expression (19) above holds. Indeed, from (27) above, we can divide through by the bracketed term on the right-hand side to obtain

\[
\frac{d\tilde{W}}{dP_D} = -\frac{\lambda D}{t_D \left( \frac{\partial D}{\partial p_D} + D \right)} + \frac{\lambda C}{t_D \left( \frac{\partial C}{\partial p_c} + C \right)} - \frac{MED \frac{\partial D}{\partial p_D}}{t_D \left( \frac{\partial D}{\partial p_D} + D \right)}
\]  

(32)

which can be written as

\[
\frac{d\tilde{W}}{dR_D} = -MCPF_D + MCPF_C - MEBPF_D.
\]  

(33)
Welfare will be maximized when the left-hand side equals zero, in which case the expression reduces to (19) above, confirming the proposition that the marginal cost of public funds should be equalized net of environmental benefits.

To see this point intuitively, figure 2 illustrates the optimal tax relation represented by (19) and (20), or when (33) is set equal to zero. To minimize the marginal cost of raising a given amount of public funds, the tax rates on D and C should be chosen to minimize the total cost of raising any given amount of revenue R. It is clear from figure 2 that up to R=RP*, only the polluting good should be taxed since the net social cost associated with each dollar of revenue collected is less than one dollar—due to the environmental improvement. Once this non-distorting source of revenue has been exhausted by taxing the dirty good up to the Pigouvian rate, how should optimal revenue-motivated taxes be assigned?

We see in figure 2 that for equal increments of additional revenue, the net MCPF rises more steeply for the dirty good than for the clean good, indicating that the optimal revenue-motivated taxes may differ between the two goods. As revenue requirements rise, more of the additional revenue will come from the clean good, but it is evident from figure 2 that tax rates on both goods should be raised (For example, equalizing these rates at MCPF1 in figure 2 will be the optimal way to collect R = R1C + R1D.) We can see implicitly from figure 2 that more revenue should always be raised from the polluting good than the clean good (although the difference between the revenue raised via the two goods diminishes as revenue requirements rise). Higher revenue requirements will be associated with lower levels of consumption of the polluting good, and therefore a cleaner environment. Whether the optimal tax differential is higher or lower than marginal environmental damages is an empirical question, depending on the sign and magnitude of the own- and cross-price elements of the Slutsky matrix.
IV. Whence appears this double dividend?

In general, the analyses that support the double dividend hypothesis have not provided an intuitive explanation for the source of the second, or double, dividend. We can understand where the first benefit comes from: it represents the allocative efficiency gains from equating marginal benefits and costs of pollution. But we have not yet established an intuitive explanation for the source of the second benefit, at least not one that builds on existing economic theory.

The intuition proposed here draws on well-established principles about taxing pure rents. Since the environment is an exogenously supplied asset, its services provide an opportunity for government to appropriate resource rents. The appeal of taxing pure rents from exogenously supplied resources is a well-known part of the contemporary literature on the taxation of exhaustible resource rents (Gray [13], Gaffney [11], and Dasgupta and Heal [9]). However, much earlier than this, Henry George [12] proposed a "single tax," or land tax, which has sometimes been interpreted broadly as a tax on natural resources. Indeed, the applicability of George’s ideas to modern environmental and resource problems has been recently pointed out (see Yandle and Barnett [28], Whitaker [27]). Although the similarity between taxing rents from exhaustible resources and taxing rents from a less tangible resource such as "location" may not at first glance be obvious, they are both examples of assets where inelastic supply makes them eminently suitable for taxation—as would other services provided by the environment.

Indeed, generally speaking, natural environments such as the air, rivers, lakes, oceans, atmosphere, and subsoil systems represent public goods (or assets) that provide services and produce commodities. This notion has not been widely applied to pollution or other environmental issues, perhaps because economists have tended to use the externality or "dirty
good" metaphor, which links consumption of a commodity directly with environmental degradation, and draws attention away from one of the important environmental services at issue—that of waste disposal. Nevertheless, among the important services nature provides is the capacity to absorb, store, or assimilate wastes generated as the residual by-products from production and consumption. In addition to serving as environmental waste sinks, these natural environments 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 (see Mäler [19]).

When flows of waste into these environments exceed their capacity to assimilate wastes, the stock effects usually manifest themselves as congestion costs affecting the quality or quantity of the environmental amenities and other services. Indeed, 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 also dissipates their potential resource rents.

Given that this assimilative capacity is one service from an exogenously supplied natural asset, the pure rents from these services can—in principle—be taxed away without distortion. By introducing a Pigouvian tax on waste disposal, government effectively restores allocative efficiency which restores the potential for rent appropriation, and at the same time appropriates the rents. Because these rents restore rather than distort allocative efficiency, they will reduce the overall social cost of the tax system if substituted for pre-existing revenue-motivated taxes.
Thus, the source of the second, or double, dividend can be seen as rent appropriation combined with the replacement of more-distortionary taxes with less-distortionary ones.

In the case of an exhaustible resource, or with George's notion of land rents, it is only the second benefit which arises (the substitution of non-distorting for distorting taxes), because we assume that land and mineral resources do not suffer from property rights failures, and thus are assumed to be allocated efficiently both before and after the introduction of the tax. The double dividend, therefore, can be seen as an extension of this existing theory to the commons, or where property rights failures have led to the misallocation and dissipation of rents. Indeed, the tax benefits from rent appropriation holds for other kinds of environmental services and congestible public goods as well, whether they are supplied by nature or have been 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 (e.g., by auctioning individual transferable quotas) would represent the appropriation of rents and would also produce the same two benefits as indicated for a waste sink’s assimilative capacity. Similarly, congestion pricing of highways, or the auctioning of riparian water rights represent other examples where the appropriation of resource rents would improve the efficiency of the tax system.⁵

V. Concluding Comments

The present analysis finds that neither Pigouvian traditions nor Ramsey rules need fundamental alteration when integrating pollution taxes with revenue-motivate taxes, or when revenue-motivated taxes preexist. It is essential, however, to recognize that an income tax is

⁵ In cases where direct taxation may not be practical—in the same way that taxing environmental amenities is not practical—optimal taxation may nevertheless be achieved through a set of indirect taxes on commodities or inputs that affect the amount of the externality produced (see Holtermann [16]). For
equivalent to a uniform tax on all expenditures, including expenditures on commodity tax payments, and that this will compound taxes being applied to commodities. As a result of this, the real, or effective tax on a commodity will exceed the nominal tax rate applied in the presence of an income tax. This observation is a general one, and has not specific or distinctive relationship to environmental taxation issues.

In general, when approaching environmental taxation issues, it is important to distinguish between nominal and effective tax rates when income and expenditure taxes interact, to recognize the symmetrical complementarity between revenue-motivated and environmentally-motivated taxes, and to clearly identify the relevant starting point for analysis of any proposed tax shift.

The importance of these issues has been highlighted by recent literature which has rejected the double dividend hypothesis. Given the complexities and subtleties that may arise, for example when using the analytical perturbation approach of Bovenberg and de Mooij where the distinction between nominal and effective tax rates may be overlooked, or in comparing results with different starting points for proposed tax reform, equations (19) and (31) would appear to offer a transparent and consistent way of identifying the optimal second-best pollution taxes and corresponding welfare gains.

To summarize the analysis, we find that in a second-best world when government uses taxes to raise revenue, the environment should be cleaner, not dirtier, than in the first-best situation. In the first-best world, the optimal tax on a polluting good will equal the Pigouvian rate, and it will be higher than the Pigouvian rate in a second best world. The second-best optimal (effective) tax on the polluting good will always be higher than the optimal tax on a

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example, differential taxation of energy sources (coal, gas, biomass, solar) according to their carbon emissions will be equivalent to a carbon tax.
similar non-polluting good, but the difference between the two optimal tax rates may be higher or lower than the Pigouvian principle would suggest. Up to the Pigouvian tax, pollution levies will produce two social benefits: they can substitute for highly distorting pre-existing taxes, and they will restore allocative efficiency of the environmental resource (reduce excess pollution). For revenue requirements that exceed this level, revenue-motivated taxes should be applied to polluting and non-polluting goods alike. With a rise in the revenue requirements of government, the optimal tax on a polluting good will rise, and the optimal level of pollution will fall.

A number of policy implications follow from this analysis. First, in the presence of taxes on labor or other sources of income, the nominal tax rate on pollution required to achieve the optimal effective tax will be lower than marginal environmental damages, but this, by itself, does not weaken the real variables of interest: the incentive, allocation, or welfare consequences associated with the effective tax.

Second, from a given second-best starting point, the magnitude of the welfare gains from taxing pollution may differ considerably from what might be expected based on the Pigouvian analysis for a reduction in environmental damages. Indeed, it is possible that the largest potential gains from taxing pollution, or equivalently from the auctioning of pollution permits, may come from the appropriation of these resource rents and use of the revenues collected to substitute for highly distortionary existing taxes. Conversely, it is also possible that, from a given starting point, preexisting taxes have already reduced pollution from what would have been a much higher (first-best) initial level, so that the remaining reductions in pollution that are required to achieve the optimal level may be small.
Finally, the higher the cost of public funds, the greater will be the benefits from taxing pollution. Conversely, the higher the costs of public funds, the greater will be the social costs of failing to tax pollution appropriately.
REFERENCES


Figure 1. The marginal cost of public funds for polluting and non-polluting goods
Figure 2. Marginal cost of public funds and optimal environmental taxation

\[ \text{MCPF}_C (= \text{MCPF}_D) \]

\[ \text{MCPF}_D - \text{MEBPF}_D \]

\[ \text{MCPF}^1 \]

\[ 1 \]

\[ R_C^1 \quad R^*_P \quad R_D^1 \]

Revenue