Comments welcome.

On the Double Dividend of Environmental Taxation*

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ABSTRACT

This paper suggests that recent literature which has rejected the double dividend hypothesis has done so erroneously due to algebraic errors and misinterpretation of results.

The present analysis validates the double dividend hypothesis in a general equilibrium framework. It demonstrates that up to the Pigouvian rate an equal yield tax reform that substitutes pollution taxes for pre-existing commodity taxes will produce two social benefits; restoring allocative efficiency by reducing excess pollution, and equalizing the marginal cost of public funds across commodities. The analysis shows that in a second-best world where governments need to raise revenue through taxes, that optimal taxation implies a cleaner, rather than a more polluted, environment than the first-best case. Moreover, a rise in the marginal cost of public funds will raise the optimal tax on a polluting good, and thus lower the optimal level of pollution. Results demonstrate that the optimal corrective tax on a polluting good is always equal to the Pigouvian rate. However, the optimal "tax differential," between similar polluting and non-polluting goods, may be higher or lower than the Pigouvian principle would suggest, but this is because the optimal revenue-motivated tax is affected by the presence of a corrective tax. These results contradict each of the claims made, for example, by Bovenberg and de Mooij (1994).

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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 well-enough 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 (1967), Kneese and Bower (1968), Terkla (1984), Lee and Misiolek (1986), and Oates (1993), among others. But the idea has recently been challenged by a number of authors who reject the double dividend hypothesis outright.

In the most-cited of these recent papers, Lans Bovenberg and Ruud A. de Mooij (1994) claim to demonstrate that "environmental taxes typically exacerbate, rather than alleviate, pre-existing tax distortions" even when introduced as part of an equal-yield tax reform. They claim further 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" and that "the marginal costs of environmental policy rise with the marginal cost of public funds." In order to explain their results, the authors suggest that "the collective good of environmental quality directly competes with other collective goods." Other papers have reinforced this result, including Bovenberg and van der Ploeg (1994), Parry (1994), Goulder (1995), Bovenberg and Goulder (1996), Goulder, Parry, and Burtraw (1996), Parry, Williams, and Goulder (1997), and Fullerton (1997). These recent analyses have attracted considerable attention, in part because of their strong claim that the double dividend intuition is wrong and that analyses based on the notion are therefore flawed (Bovenberg and de Mooij 1997; Fullerton 1997).

In this paper I will suggest that these authors' have mistakenly rejected the double dividend hypothesis. This is so for several reasons. In the specific case of Bovenberg and de Mooij, they have made an algebraic error and introduced the wrong optimal tax into their model. Rather than introducing the Pigouvian tax as a starting point, they have unwittingly introduced a tax higher than the Pigouvian tax. From this starting point, they detect a welfare gain from lowering the tax below this starting point--but this is precisely because they are moving toward the Pigouvian tax rate, not away from it.

More generally, these analyses have blurred the distinction between the corrective and revenue-motivated components of the taxes being applied, and they have misleadingly focused on the optimal tax *rates* rather than the corresponding optimal *levels* of pollution, or the size of the associated welfare benefits. In several cases they have assumed that the optimal revenue-raising tax is unaffected by the presence of a corrective tax. Thus when they assess the magnitude of the optimal corrective tax as the residual share of the total optimal tax, they are led to the conclusion that the Pigouvian principle must be modified, and that the well-established Ramsey formulas must be altered (Bovenberg and Goulder 1996; Fullerton 1997). In still other cases, the analyses have lost sight of the first-best starting point from which to measure the difference between private and social costs (Parry 1994; Parry, Williams, Goulder 1996).

The main purpose of this paper is to show that neither Ramsey formulas nor Pigouvian principles need fundamental alteration in the context of environmental taxation and that the double dividend hypothesis is, in fact, valid. Indeed, the present analysis concludes that in a second-best world where government uses taxes to raise revenue: a) taxing pollution will typically alleviate pre-existing tax distortions, b) the optimal (corrective) 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.

In order to develop these results in detail, the remainder of the paper is organized as follows. Section I describes the algebraic error in the Bovenberg and de Mooij analysis; Section II focuses on the central issue of how the marginal cost of public funds is altered when corrective taxes interact with revenue-motivated taxes. Section III addresses the double dividend hypothesis directly by identifying the welfare effects of environmental tax reform. Section IV provides an intuitive explanation for the double dividend, and section V concludes.

I. Nominal versus effective pollution tax rates

In their widely cited paper, Bovenberg and de Mooij 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 R 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 effects 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 (Atkinson and Stiglitz, 1972). Since Bovenberg and de Mooij take the clean good to be the numeraire and employ a labor tax, it follows that the optimal tax on the dirty good will be zero as well. Alternatively, we understand that a labor tax is equivalent to a uniform tax on all commodities, so that when the utility function is homothetic we can employ a labor tax as an instrument to achieve optimal taxation (Auerbach 1985). This equivalence between the labor tax and uniform commodity taxes will be true whether labor income is multiplied by $(1-t_L)$ or whether all expenditures are multiplied by $(1+t)$ so long as $(1+t) = 1/(1-t_L)$.

This equivalence, however, is complicated when a corrective tax on an externality enters the model. Because a labor tax is equivalent to a uniform tax on all expenditures, and because a corrective tax on the dirty good must be paid as part of those expenditures, then the labor tax is equivalent to applying a uniform tax not only on the dirty good, but on the corrective tax as well, compounding the effective tax rate on pollution. We will use the notation that the nominal pollution tax is $t_{D,}$ but where a labor tax effectively compounds this tax rate, the "effective" tax on the dirty good is τ_D. Thus, we can assume that in the absence of other taxes these two will be equal, and that their optimal values will then both be denoted as $\tau^*_D = t^*_D$. In the presence of a labor tax, however, if we want the optimal *effective* tax on the externality to be equal to the marginal external cost, or the Pigouvian tax τ^*, the nominal corrective tax must be 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. This implies that the effective tax rate in their model, intended to be the Pigouvian starting point, τ^0_D, will be too high since $\tau^0 = t^*_D\ (1/1\text{-}t_L) > \tau^*_D$.

This can be seen directly by taking Bovenberg and de Mooij's expenditure constraint (2)

$$C + (1 + t_D)D = h(1\text{-}t_L)(1\text{-}L),$$

where h is the population and dividing through by $(1\text{-}t_L)$ to get

$$\frac{C}{(1-t_L)} + \frac{(1+t_D)D}{(1-t_L)} = h(1-L)\ .$$

showing the equivalence between a labor tax and commodity taxes equal to $1/1\text{-}t_L$. If $t_D = 0$ then the effective tax on D is $(1/1\text{-}t_L)$, and we can see also that the introduction of a corrective tax t^*_P (=MEC) would raise the price of D by $t^*_P/(1\text{-}t_L)$ or by more than t^*_P. Thus, while they believe they have set the corrective tax optimally (according to the Pigouvian principle), in reality they have set it too high. We can see this problem in figure 1. Starting with a good D supplied at constant cost, P_0, the presence of a labor tax can be represented as equivalent to a tax $t_D = 1/1\text{-}t_L$. In order to introduce the Pigouvian tax as the effective tax rate, one would have to introduce a nominal tax on the commodity equal to $P^*_D(1\text{-}t_L)$. Since, in the Bovenberg and de Mooij model the corrective tax is paid out of income earned in the labor market, the corrective tax is itself implicitly subject to the labor tax. Thus they have introduced a tax which raises the price of D to $(P_0 + t^*_P)^*(1/1\text{-}t_L)$ instead of the desired level of $P_0(1/1\text{-}t_L) + t^*_P$.

From this starting point Bovenberg and de Mooij examine the welfare effects of a small reduction in the corrective tax on the dirty good below t_D^*. From their equation (5) where they have the welfare impact as

$$\frac{dU}{\lambda} = ht_L dL + \left[t_D - N \frac{\partial u}{\partial E} \left(-\frac{de}{d(ND)} \right) \frac{1}{\lambda} \right] dD \qquad [1]$$

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

$$t^*_D = N \frac{\partial u}{\partial E} \left(-\frac{de}{d(ND)} \right) \frac{1}{\lambda} \qquad [2]$$

Their interpretation certainly holds for the tax rate they have introduced, but they have introduced the wrong tax rate. Welfare is improving because their marginal reduction in the corrective tax represents a movement toward the Pigouvian rate, not away from it. If instead of setting the initial nominal tax rate equal to the Pigouvian rate, Bovenberg and de Mooij had instead set it such that the effective tax rate was optimal ($t_D = \tau^*_D(1-t_L)$) then their relation (5) would be

$$\frac{dU}{\lambda} = ht_L dL + \left[\tau^*_D (1-t_L) - N \frac{\partial u}{\partial E} \left(-\frac{de}{d(ND)} \right) \frac{1}{\lambda} \right] dD. \qquad [3]$$

With the optimal tax on the dirty good introduced correctly, we see that the second term on the right-hand side is negative since $\tau^*_D(1-t_L) < \tau^*_D$, and thus the sign of the welfare change for a reduction in t_D below t_D^* is ambiguous. This modification eliminates the basis for the Bovenberg and de Mooij conclusion; they have not established their claim that the optimal corrective tax should be lower than the Pigouvian rate.[1]

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[1] Not surprisingly, when these authors have made numerical estimations of the magnitude of the pollution "subsidy" necessary to achieve optimality, they have concluded that the

The distinction between nominal and effective tax rates is a technical issue involving accounting identities and the choice of tax instruments, and it is also a practical matter underscoring the importance of distinguishing between nominal and effective tax rates. However, since it is not a theoretical point, it should not distract attention from resolving the debate over the double dividend.[2]

II. The marginal cost of public funds in the presence of corrective taxes

The above technical issue notwithstanding, there is still a question of whether the total tax on a polluting good will be higher or lower than the sum of the first-best corrective tax and the (independently estimated) optimal revenue-raising tax. It will be shown below that the optimal (total) tax may be higher, or lower, than the sum of these two tax rates when measured independently. However, it will also be shown that it is the optimal revenue-motivated tax, not the optimal corrective tax, that is altered when both taxes are present. Finally, it will be shown that the interaction of these two taxes results in a *cleaner*, not a dirtier, environment.

The measure of the marginal cost of public funds is key to a clear understanding of how corrective and revenue-motivated taxes interact. Assume initially that we have a corrective tax t^P (using the superscript P to indicate the corrective, or pollution, tax and

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optimal pollution tax will equal approximately $(1- t_L)$ times the Pigouvian rate (Bovenberg and Goulder 1996).

[2] Although Bovenberg and de Mooij (1997) broach a related question in response to the normalization issue raised by Fullerton (1997), their comments do not appear to address the point being raised here. If they mean to suggest, however, that as a practical matter it is the nominal tax rate that matters to people, they may have a point—at least as a practical matter. But since the double dividend hypothesis is a theoretical debate, not a practical one, it must be addressed and resolved in theoretically clear terms, including terms that distinguish between nominal and effective rates of taxation.

superscript R for the revenue-motivated tax) on the dirty good, setting it equal to the optimal, or Pigouvian, rate t^P* so 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…” (Ramsey 1927, 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 (for example, 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. This, however, would be incorrect. 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

$$MCPF_X = \frac{Xdt}{Xdt + t\dfrac{dX}{dt}dt} = \frac{X}{X + t\dfrac{dX}{dt}} \qquad [4]$$

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 $\boldsymbol{\tau}^R$ will be

$$MCPF_C = \frac{C}{C + \tau^R \frac{dC}{dt}} \cong \frac{C}{C} \qquad [5]$$

and will be approximately equal to 1 for an arbitrarily small τ^R. 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 τ^R will be

$$MCPF_D = \frac{D}{D + (t^P * + \tau^R)\frac{dD}{dt}} > 1 \qquad [6]$$

Since the second term in the denominator will be positive ($t^P* + \tau^R > 0$), we can see that the $MCPF_D$ will exceed one.

This difference is illustrated in figure 2 where the 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 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 $MCPF_D$ 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 the initial source of revenue, the corrective tax. However, this difference will be partially offset by the additional improvements in environmental quality.

How does this 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 the net environmental benefit of reducing pollution (per dollar of revenue collected) is included. For a world with a clean good C and a polluting good D, therefore, we would want to equate

$$MCPF_C = MCPF_D - MEBPF_D \qquad [7]$$

where MEBPF is the marginal environmental benefit arising (unintentionally) 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

$$\frac{\lambda C}{C + t_C \dfrac{dC}{dP_C}} = \frac{\lambda D}{D + t_D \dfrac{dD}{dP_D}} - \frac{N \dfrac{\partial U}{\partial E} \dfrac{de}{dD} \dfrac{dD}{dP_D}}{D + t_D \dfrac{dD}{dP_D}} \qquad [8]$$

where again environmental quality E = e(ND) and N is the number of households, and where λ 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 $\mu = MCPF_C$ and write the above formula as

$$\mu = \frac{\lambda D}{D + t_D \frac{dD}{dP_D}} - \frac{N \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}}{D + t_D \frac{dD}{dP_D}} \qquad [9]$$

which can be rearranged as

$$D + t_D \frac{dD}{dP_D} = \frac{\lambda D}{\mu} - \frac{N}{\mu} \frac{\partial U}{\partial E} \frac{de}{dD} \frac{dD}{dP_D}. \qquad [10]$$

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

$$t_D = \frac{-D}{\frac{dD}{dP_D}} + \frac{\lambda}{\mu} \frac{D}{\frac{dD}{dP_D}} - \frac{N}{\mu} \frac{\partial U}{\partial E} \frac{de}{dD}. \qquad [11]$$

Collecting terms and dividing through by P_D produces

$$\frac{t_D}{p_D} = \left(1 - \frac{\lambda}{\mu}\right) \frac{-1}{\frac{dD}{dP_D} \frac{P_D}{D}} - \frac{N}{P_D \mu} \frac{\partial U}{\partial E} \frac{de}{dD}. \qquad [12]$$

From this point we can substitute the efficiency condition $p_D \lambda = \partial U / \partial D$ and $\phi = \lambda / \mu$ to write the relation as

$$\frac{t_D}{p_D} = (1 - \phi) \frac{-1}{\eta_{DD}} - \phi N \frac{\frac{\partial U}{\partial E} \frac{de}{dD}}{\frac{\partial U}{\partial D}} \qquad [13]$$

where η_{DD} is the own price elasticity of demand. We can now see that this is the same as Sandmo's well-known result (1975, p. 93) for the optimal tax rate in the presence of externalities. This equivalence confirms 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.

Sandmo's result, however, is easy to misinterpret. For example, in a recent defense of Bovenberg and de Mooij's analysis, Fullerton (1997) interprets Sandmo's result as showing that the total tax on the dirty good will be "a weighted average of a revenue raising Ramsey term (R) and the marginal environmental damage (τ)..."(p. 248), implying that the total optimal tax will be between the Pigouvian rate and the Ramsey rate. But this interpretation is wrong. The first term on the right-hand side is not a fraction of the Ramsey term, it *is* the Ramsey term. It is easy to see that we can apply this same expression to a clean good if we simply set MEC = 0. Thus, the second term simply drops out, leaving only the first term. It must be clearly stated that the entire first term is the "Ramsey term" and the total tax on the polluting good will be higher than the Ramsey tax.

Further interpretation by Fullerton leads him to suggest that since the marginal environmental damage is weighted by a fraction less than one, that "the environmental component…is less than the Pigouvian rate" and that, therefore "an increase in government revenue requirement means an increase in the distortionary effects of taxes, a higher [μ], more weight on the revenue-raising term, and less weight on the marginal environmental damage"(p. 248). Thus, he supports the claim of Bovenberg and de Mooij that a higher cost of public funds necessarily competes with the goal of maintaining a clean environment. There are two errors in this interpretation.

First, the particular separation of terms in the Sandmo formulation should not be taken as proof that it is the corrective versus the revenue tax that is altered when both are present. Fullerton, along with Bovenberg and de Mooij, has mistakenly assumed that the optimal revenue-motivated tax is unchanged in the presence of a preexisting corrective tax. Therefore they assess the optimal corrective tax as a residual component of the total optimal tax, and conclude—based on their analysis—that it is reduced below the Pigouvian rate. Since it is the marginal cost of public funds that is altered when a corrective tax is in place, however, a better interpretation would appear to be that the optimal revenue-motivated tax, not the optimal corrective tax, is affected.

Nevertheless, since both tax components serve dual purposes (of raising revenue and discouraging pollution), the question of which component of the total optimal tax is larger or smaller than expected will not be a fruitful debate beyond the apparent need for theoretical clarification. A much more important question involves the state of 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? On this point, neither Bovenberg and de Mooij nor Fullerton appears to recognize that although the total optimal tax on the polluting good may differ from the sum of the two individually-estimated taxes, the second-best optimum will always correspond to a *lower* level of pollution—a cleaner environment, not a dirtier one—than that which would be optimal at the first best Pigouvian rate.

To see this important point clearly, figure 3 illustrates the optimal tax problem represented by [7] and [8] above. 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 3 that up to $R=R^{P}*$, only the polluting good should be taxed since the net social cost associated with this tax is negative 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 3 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 3 that tax rates on both clean and dirty goods should be raised (For example, equalizing these rates as $MCPF^1$ in figure 3 will be the optimal way to collect $R = R^1_C + R^1_D$.) We can see implicitly from figure 3 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). This implies that higher revenue requirements will be associated with lower levels of consumption of the polluting good, and therefore a cleaner environment.

The second error in interpretation made by Fullerton (1997) and by Bovenberg and de Mooij (1997) has to do with the claim that the "tax differential", the difference in the optimal tax rates between the clean and dirty goods, will be less than the marginal environmental damage. We have seen in section I above that Bovenberg and de Mooij have come to this conclusion through an error in failing to distinguish between nominal and effective tax rates (ignoring a direct and explicit "tax interaction effect," while claiming to have uncovered a more subtle and unrecognized one). Yet Fullerton has attempted to confirm this same result in a more transparent fashion by referring to the Sandmo result in [13]. Fullerton describes the second term in [13] as being the marginal environmental damage multiplied by ϕ, the ratio of the marginal utility of income (λ) to the marginal cost of public funds, μ. If we normalized the marginal utility of income to be one, we see that this ratio is less than one, so that the second term is a fraction of the marginal environmental damage. Based on this Fullerton concludes that "thus, the environmental component …is less than the Pigouvian rate."

This, however, neglects the fact that this equation must be solved simultaneously with the identity, $P_D = P^0_D + t_D$. The left-hand side is a tax rate (the ratio of tax to price) where the price is inclusive of both revenue and corrective components of the tax.[3] Therefore, a higher tax on the dirty good raises the base (p) of the tax rate (t/P), whether the increase in the tax has resulted from the first or second term in the optimal tax relation. True, the second term on the right-hand side of [13] is the ratio of the marginal environmental damage to the marginal utility of the dirty good multiplied by a fraction less than one. But as the revenue motivated tax term increases, the tax/price ratio will exceed the ratio of marginal environmental damages to marginal utility of consumption for the dirty good because of the inclusion of the revenue-motivated tax. We can see this clearly by manipulating the formula.

If we normalize the marginal utility of income to be one, we can rewrite [13] as

$$t_D = \left(1 - \frac{1}{\mu}\right)\frac{-p_D}{\eta_{DD}} - \frac{1}{\mu} N \frac{\partial U}{\partial E}\frac{de}{dD}. \qquad [14]$$

We can see that for μ > 1 Fullerton is correct to point out that the second term is less than the Pigouvian tax, but it is *also* true that the first term is *greater* than the Ramsey rate (for

[3] Although Fullerton defines τ as the "dollar cost of environmental damage per unit of the dirty output"(p.246), he later describes the second term of Sandmo's result to be (1/μ)τ where he says that τ is the Pigouvian tax rate (t/p). Moreover, to be correct the second term of Sandmo's relation should be divided by the marginal utility of the dirty good, or equivalently its price if we assume λ=1.

clean goods) since the price is pushed higher by the extra corrective tax. With the first term higher than the Ramsey tax, and the second term lower than the Pigouvian tax, we *cannot* conclude that the total optimal tax on the polluting good is less than the sum of the Ramsey tax and the Pigouvian tax. Although Fullerton is right that a higher μ will shift "more weight on the revenue-raising term, and less weight on the marginal environmental damage" but since that first term in larger in the case of the dirty good than the clean good, shifting the weight toward the first term will tend to raise the tax differential. Thus it is ambiguous whether the ratio $1/\mu$ implies that the total tax is less than the sum of the two independently-estimated components.

Despite the claims of Fullerton (1997), Bovenberg and de Mooij (1994, 1997), and others, we cannot say that the "tax differential" (the difference in the optimal tax rates between a dirty good and an equivalent clean good with both revenue taxes and corrective taxes) will be reduced. A straightforward way to answer this question would be to 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. Setting the marginal utility of income and the before-tax prices of D and C equal to one, we have the identities $P_D = P^0_D + t_D = 1 + t_D$ and $P_C = P^0_C + t_C = 1 + t_C$. By assuming, as Bovenberg and de Mooij do, that both goods are homothetic in utility and hence have equal and constant elasticities of demand, we can write the optimal tax on the clean good as

$$t_C = \left(1 - \frac{1}{\mu}\right)\frac{-(1+t_C)}{\eta} \qquad [15]$$

and the optimal tax on the dirty good as

$$t_D = \left(1 - \frac{1}{\mu}\right)\frac{-(1+t_D)}{\eta} - \frac{1}{\mu}MEC \qquad [16]$$

where the marginal environmental damage, or cost, is MEC. We want to evaluate the difference between these two optimal taxes, or

$$t_D - t_C = \left(1 - \frac{1}{\mu}\right)\frac{-(1+t_D)}{\eta} - \frac{1}{\mu}MEC - \left(1 - \frac{1}{\mu}\right)\frac{-(1+t_C)}{\eta} \qquad [17]$$

which can be written as

$$t_D - t_C = \left(1 - \frac{1}{\mu}\right)\frac{(t_C - t_D)}{\eta} - \frac{MEC}{\mu}$$

or

$$\frac{(t_D - t_C)}{(t_C - t_D)} = \left(1 - \frac{1}{\mu}\right)\frac{1}{\eta} - \frac{1}{\mu}\frac{MEC}{(t_C - t_D)} = -1$$

Rearranging terms we can write this as

$$-\frac{\eta}{\eta} - \frac{1}{\eta} + \frac{1}{\mu\eta} = -\frac{1}{\mu}\frac{MEC}{(t_C - t_D)}$$

and the tax differential can now be isolated to give

$$t_D - t_C = \frac{MEC}{(\frac{1}{\eta} - \mu - \frac{\mu}{\eta})} \qquad [18]$$

By inspection we can see that if the elasticity of demand 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 MEC. If $\eta < 1$, the optimal tax differential will be greater than MEC, and if $\eta > 1$, the tax differential will be less than MEC.[4]

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[4] If we assume that the own-price elasticity is indeed equal to one, we can return to the corrected version of the Bovenberg and de Mooij relation in [3] above and set it equal to zero. The relation can then be rearranged to give us $dL/dD = \tau^*/h$, the interpretation of which provides a more plausible intuition, that the optimal tax will equate the marginal adjustment at both the leisure and environmental margins (margins for untaxable "goods") to the ratio of their marginal costs.

A simple numerical example makes the point. For example, consider two similar goods, one clean and one polluting, produced at constant cost so that $P^0 = 100$ for both. For the polluting good assume MEC is constant at 20, and that the own price elasticities for both goods, η_{DD} and η_{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 is constant at $\mu = 1.25$.

For the clean good we can use [15] above and combine it with the identity $P_C = P^0_C + t^*_C$ to estimate the optimal tax as

$$t_C = \left(1 - \frac{1}{\mu}\right)\frac{-1}{\eta}\, p_C$$

or

$$t_C{*} = \left(1 - \frac{1}{1.25}\right)\frac{-1}{-1} \cdot (100 + t_C{*}) = 0.2 \cdot (100 + t_C{*}) = 80 + 0.2t_C{*}$$

$$0.8t_C{*} = 20$$

$$t_C{*} = 20/0.8 = 25$$

For the dirty good we can similarly estimate the optimal tax using [16] and the same identity as above to get

$$t_D = \left(1 - \frac{1}{1.25}\right)\frac{-1}{-1}(100 + t_D) + \frac{20}{1.25} = 0.2(100 + t_D) + 16 = 80 + 0.2t_D + 16$$

$$0.8t_D = 36$$

$$t_D = 36/0.8 = 45$$

And finally, we can see that the tax differential equals MEC;

$$t_D - t_C = 45 - 25 = 20.$$

Thus a simple numerical example demonstrates Fullerton's erroneous interpretation of Sandmo's result. Sandmo appears to have also misinterpreted his own result as representing “a weighted average of the inverse elasticity and the marginal social damage”(p. 93).

Although this tells us that the optimal environmental "tax differential" may be higher or lower than the marginal environmental damage, a central question remains; Do revenue raising goals conflict with environmental goals? What these results suggest is that public finance goals and environmental goals are complementary. It is not correct to say that environmental taxes 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. The collective good of environmental quality is a complement to, not a competitor with, the provision of other collective goods. This result is quite the opposite of the strong claims made by Bovenberg and de Mooij (1994), Bovenberg and van der Ploeg (1994), Bovenberg and Goulder (1996), Fullerton (1997), and Parry (1995).

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 $V(U(C(\mathbf{P},Y), D(\mathbf{P},Y), E(hD), L(\mathbf{P},Y)))$. Leaving leisure as the untaxed good, but where $P_D = P^0_D + t_D$ and $P_C = P^0_C + t_C$, the optimal tax problem can be characterized as

$$\underset{P}{MAX}\ \ V(P_C, P_D, E, w) \text{ subject to } (t_D D + t_C C = R). \qquad [19]$$

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

$$\frac{\partial V}{\partial P_D} = -\lambda D + \mu\left[t_D \frac{\partial D}{\partial p_D} + D\right] + h\frac{\partial U}{\partial E}\frac{de}{dD}\frac{\partial D}{\partial p_D} \qquad [20]$$

and

$$\frac{\partial V}{\partial P_C} = -\lambda C + \mu\left[t_C \frac{\partial C}{\partial p_C} + C\right]. \qquad [21]$$

Beginning with equal revenue raising taxes ($t^0_D = t^0_C < t^{P*}$) on both goods, we want to assess the welfare effects of an equal yield tax shift to introduce a corrective tax on the polluting good to raise the total tax up to the Pigouvian level t^{P*}. With the welfare effects of an increase in the tax (price) of each good given by [20] and [21], the welfare change per dollar of revenue can be written as $\frac{dV}{dP_J}\frac{dP_J}{dR}$. Defining $\widetilde{W}$ 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

$$\frac{d\tilde{W}}{dR_D} = \frac{dV}{dP_D}\frac{dP_D}{dR} - \frac{dV}{dP_C}\frac{dP_C}{dR} \qquad [22]$$

or alternatively as

$$\frac{d\tilde{W}}{dP_D} = \frac{d\tilde{W}}{dR}\frac{dR}{dP_D} = \frac{dV}{dP_D} - \frac{\partial V}{\partial P_C}\frac{\frac{dR}{dP_D}}{\frac{dR}{dP_C}}.$$

Substituting [20] and [21] and writing dR/dP_D and dR/dP_C explicitly, we have

$$\frac{d\tilde{W}}{dP_D} = -\lambda D + \mu\left[t_D\frac{\partial D}{\partial p_D} + D\right] + h\frac{\partial U}{\partial E}\frac{de}{dD}\frac{\partial D}{\partial p_D} - \left[-\lambda C + \mu\left(t_C\frac{\partial C}{\partial p_C} + C\right)\right]\frac{\left(t_D\frac{\partial D}{\partial p_D} + D\right)}{\left(t_C\frac{\partial C}{\partial p_C} + C\right)}$$

which can be simplified as

$$\frac{d\tilde{W}}{dP_D} = -\lambda D + \lambda C\frac{\left(t_D\frac{\partial D}{\partial p_D} + D\right)}{\left(t_C\frac{\partial C}{\partial p_C} + C\right)} - MEC\frac{\partial D}{\partial p_D}$$

and further as

$$\frac{d\tilde{W}}{dP_D} = -\lambda D + \mu_C\left(t_D\frac{\partial D}{\partial p_D} + D\right) - MEC\frac{\partial D}{\partial p_D}. \qquad [23]$$

Rearranging this and assuming $\lambda = 1$ we can write

$$\frac{d\tilde{W}}{dP_D} = (\mu_C - 1)D + \mu_C t_D\frac{\partial D}{\partial p_D} - MEC\frac{\partial D}{\partial p_D}$$

or as

$$\frac{d\tilde{W}}{dP_D} = (\mu_C - 1)D + (\mu_C - 1 + 1)t_D \frac{\partial D}{\partial p_D} - MEC \frac{\partial D}{\partial p_D}$$

which in turn can be written as

$$\frac{d\tilde{W}}{dP_D} = (\mu_C - 1)D + \mu_C t_D \frac{\partial D}{\partial p_D} - t_D \frac{\partial D}{\partial p_D} + t_D \frac{\partial D}{\partial p_D} - MEC \frac{\partial D}{\partial p_D}. \quad [24]$$

Collecting terms this can be written as

$$\frac{d\tilde{W}}{dP_D} = (\mu_C - 1)\left(D + t_D \frac{\partial D}{\partial p_D} \right) + \left[t_D \frac{\partial D}{\partial p_D} - MEC \frac{\partial D}{\partial p_D} \right]. \quad [25]$$

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

$$\tilde{W}(t^P *) = \int_{t^0}^{t^{P*}} (\mu_C - 1)\left(D + t_D \frac{\partial D}{\partial p_D} \right) + \int_{t^0}^{t^{P*}} \left[t_D \frac{\partial D}{\partial p_D} - MEC \frac{\partial D}{\partial p_D} \right] \quad [26]$$

As long as $t^0 < t^P*$, the welfare effects for this tax reform will exceed the traditional Pigouvian benefits. Once the Pigouvian tax has been reached, the second term in [25] 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. Thus the welfare effects of the optimal equal-yield tax reform will be when the tax on the polluting good is raised to t**, or until marginal changes in the first and second terms of [25] are offsetting or

$$\tilde{W}(t**) = \int_{t^0}^{t^{**}} (\mu_C - 1)\left(D + t_D \frac{\partial D}{\partial p_D} \right) + \int_{t^0}^{t^{**}} \left[t_D \frac{\partial D}{\partial p_D} - MEC \frac{\partial D}{\partial p_D} \right] \quad [27]$$

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 [7] above holds. Indeed, from [24] above, we can divide through by the numerator of the second term, we obtain

$$\frac{\frac{d\tilde{W}}{dP_D}}{\left(t_D \frac{\partial D}{\partial p_D} + D\right)} = -\frac{\lambda D}{\left(t_D \frac{\partial D}{\partial p_D} + D\right)} + \frac{\lambda C}{\left(t_C \frac{\partial C}{\partial p_C} + C\right)} - \frac{MEC \frac{\partial D}{\partial p_D}}{\left(t_D \frac{\partial D}{\partial p_D} + D\right)} \qquad [28]$$

which can be written as

$$\frac{d\tilde{W}}{dR_D} = -MCPF_D + MCPF_C - MEBPF_D \qquad [29]$$

and welfare will be maximized when the left-hand side equals zero, in which case the expression reduces to [7] above.

For clarity three distinct components of the welfare benefits from introducing a tax on a polluting good (including those gains what would arise if the good were non-polluting) are identified in figure 4. The first welfare effect is the usual Pigouvian welfare gain of improved allocative efficiency (AE) from internalizing the external costs due to excessive environmental pollution. This welfare gain is identified by the triangle AE. The second benefit comes from the substitution of a non-distorting source of revenue for a distortionary source of revenue. Up to the Pigouvian tax rate, a tax on pollution will raise revenue but will not represent a (net) distortionary tax. If we assume that the tax base is large relative to potential revenue from good D, then we can assume that the MCPF for preexisting taxes is constant. The marginal benefit curve for broadening the tax base will equal (μ-1)(D +t(dD/dt) from [25] above. Thus, the marginal benefit of substituting tax revenue from good D for those from other goods is shown by the marginal tax base benefit (MTBB) curve in figure 4. This welfare benefit is identified as the trapezoid RA in figure 4. Together these two welfare changes correspond to the benefits from taxing the polluting good up to the point where in figure 3 an amount of revenue $R^{P}*$ is collected.

The third benefit comes from taxing the polluting good at a rate above the Pigouvian level in order to broaden the tax base and equate the net marginal cost of public funds across all goods. This represents a tax which raise the price of the good above its first-best price, and thus this third benefit exists for both polluting and non-polluting goods since it simply represents the broadening of the tax base. The optimal tax rate when this effect is included corresponds in figure 4 to a rise in the tax rate to $P_0 + t^{P}* + t^{R}*$ and a reduction in quantity demanded to the "fully optimal" level D^{**}. This tax base benefit is identified as TB in figure 4. The magnitude of this third benefit will be smaller for a the polluting good than for a non-polluting good as explained above.

It is easy to see from [27] that the welfare benefits from taxing a polluting good will rise with the marginal cost of public funds, $\mu_{C,}$ since they are proportional to (μ_C -1), and also because a higher μ_C implies a higher t** and therefore an larger range overwhich the integral will accrue positive welfare changes.

Intuitively the welfare gains from substituting a non-distorting tax for a distorting tax rise the higher is the marginal distortionary cost of preexisting taxes. Or, to formulate the point in terms of policy, the social cost of *not* taxing pollution at appropriate levels rises with the marginal cost of public funds.

IV. Whence appears this double dividend?

In the above analysis, as with the models of Bovenberg and others, the source of the second benefit, or double dividend, is a mystery—a fact that has likely contributed to skepticism about the validity of the double dividend hypothesis. We can understand where the first benefit comes from: it represents the allocative efficiency gains from equating marginal benefits and costs of pollution. Similarly the third benefit, the gains from broadening the revenue-raising tax base to equate marginal costs of public funds across all goods, is also understood to be the improved efficiency of the tax system. 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. Providing such an explanation would likely be an important factor in gaining acceptance of the validity of the double dividend hypothesis.

The mystery can be solved quite simply with the application of well-established principles about taxing pure rents. Since the environment is an exogenously supplied asset, the rents from 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 and long-established part of the literature on the taxation of exhaustible resource rents (Gray 1914, Gaffney 1967, Dasgupta and Heal, 1979). Similarly, Henry George (1879) is best known for his proposed "single tax," a tax on pure ground rents that would effectively tax away the pure rents associated with location.

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. Yet this notion has not been applied to pollution, 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.

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. Among the important services they provide 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 (Mäler 1985). 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 of 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 double dividend can be clearly identified as rent appropriation and, hence, the designation of the benefit as RA in figure 4.

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 can be used to improve the efficiency of the tax system.[5]

V. Concluding Comments

It is ironic—once again—that at a moment when the Pigouvian tradition has some hope of broader acceptance in application it should find itself under a cloud in the theoretical literature. This paraphrase of William Baumol (1972) from 25 years ago is apt given recent challenges to the Pigouvian tradition in the context of the double dividend debate. The analysis presented here confirms that neither Ramsey formulas nor Pigouvian traditions need alteration when integrating revenue-raising taxes and corrective taxes, or when considering the introduction of pollution taxes when revenue-motivated taxes preexist. In approaching this complex issue, however, it is important to distinguish between nominal and effective tax rates when direct and indirect taxes interact, to recognize the symmetrical complementarity between revenue-motivated and environmentally-motivated taxes, and to clearly identify the appropriate first-best equilibrium as a starting point.

The importance of these issues has been highlighted by recent literature which has mistakenly rejected the double dividend hypothesis. Given the potential for confusion

[5] In cases where direct taxation of waste disposal 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 those commodities or inputs that have an effect on the amount of the externality produced (Holtermann, 1976). For example, if taxing carbon emissions directly is too costly, an equivalent result may be achieved by differential taxation of energy sources (coal, gas, biomass, solar) according to their carbon emissions. 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 income).

due, for example, to the use of the "perturbation approach" of Bovenberg and de Mooij, and also in estimating the appropriate first- and second-best equlibria and tax rates, equations [7], [17], and [27] would appear to offer more straightforward and transparent ways of identifying the optimal second-best pollution taxes and corresponding welfare gains than other approaches.

In sum, we find that in a second-best world when government must use 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 tax on the polluting good will always be higher than the optimal tax on a 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.

There are a number of policy implications that follow from this analysis.

First, in the presence taxes on labor or other sources of income, the appropriate *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 imply a lowering of the welfare gains from such a 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 estimates of the marginal environmental damages. Indeed, as figure 4 suggests, the largest potential gains from taxing pollution may come from the appropriation of resource rents and using the revenues collected to substitute for existing distortionary taxes.

And third, the higher the cost of public funds, the greater will be the benefits from taxing pollution. Or conversely, the higher the costs of public funds, the greater will be the social costs of failing to tax pollution appropriately. The merits of maintaining a clean environment are strengthened with a rise in the desired level of provision of other public goods.

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Figure 1. The compounding effect of a labor tax on corrective taxes.

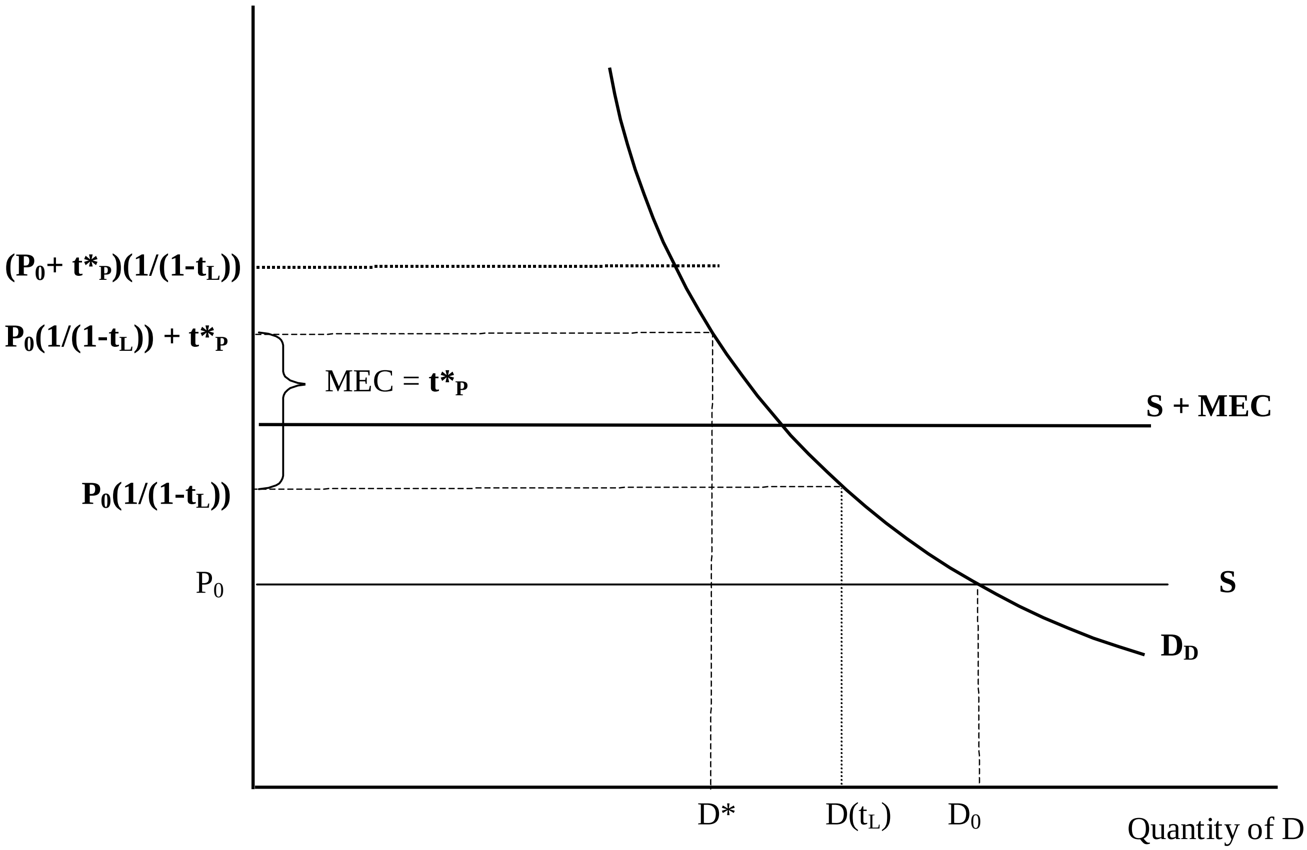

Figure 2. The marginal cost of public funds for polluting and non-polluting goods

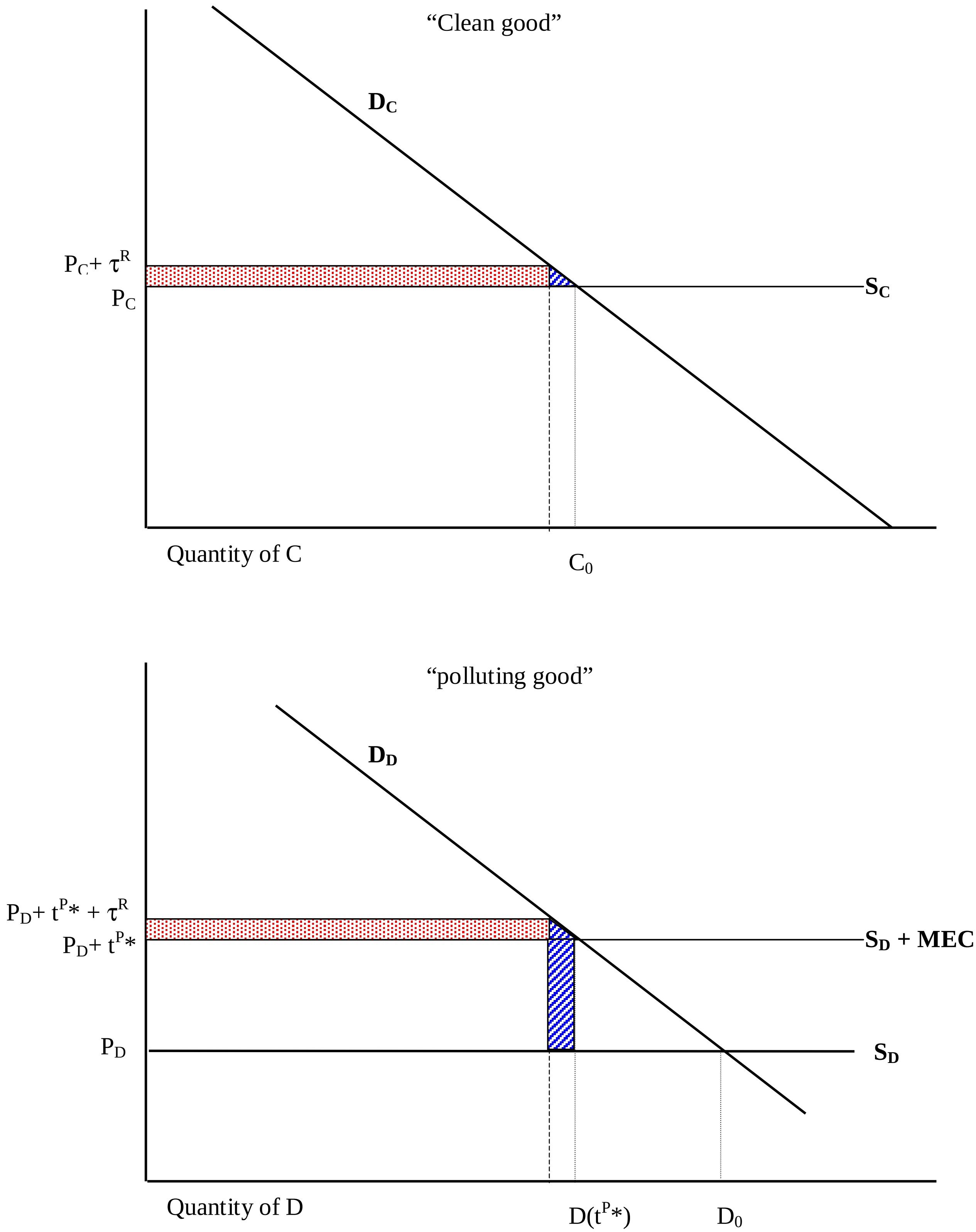

Figure 3. Marginal cost of public funds and optimal environmental taxation

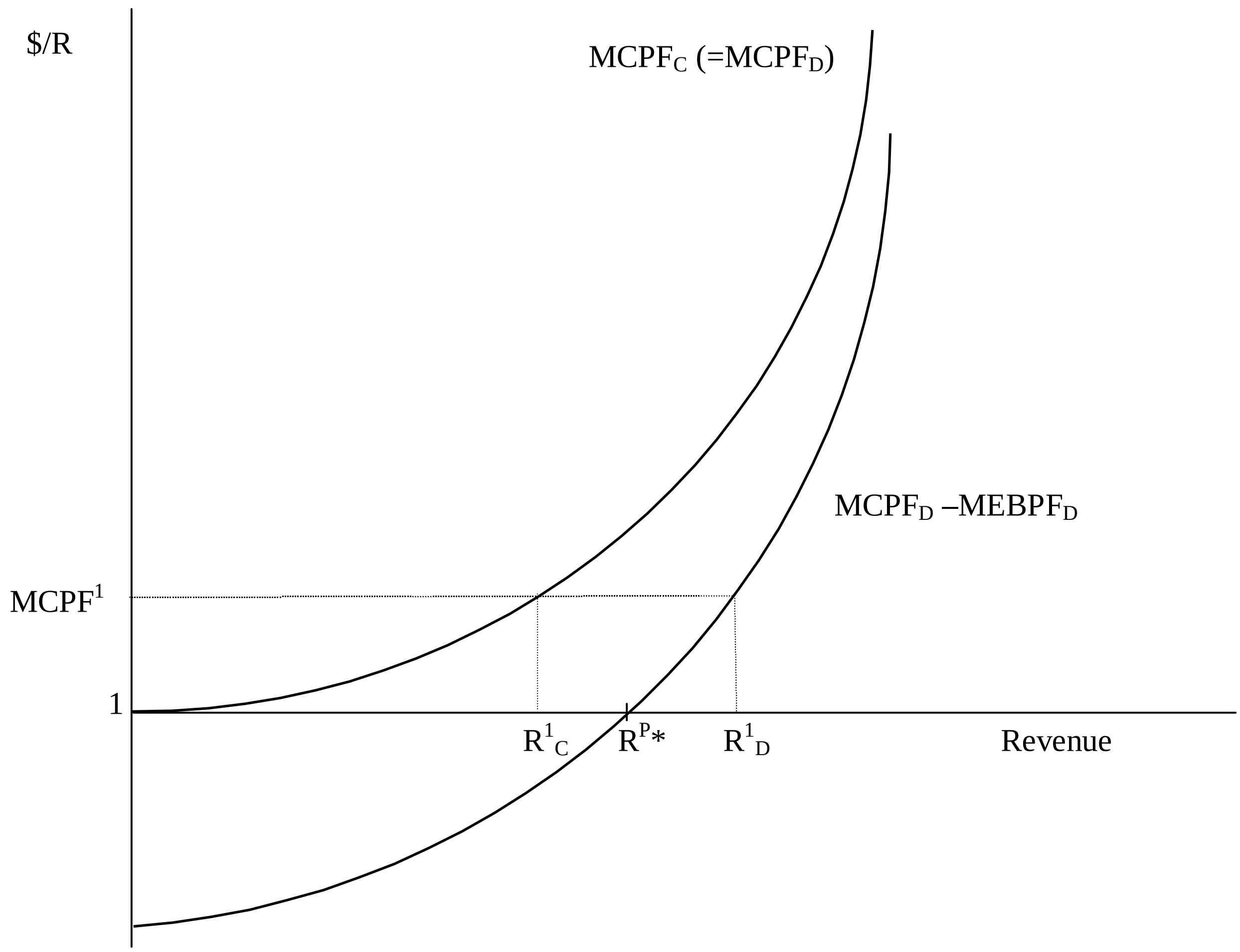

Figure 4. Welfare effects of second-best environmental taxation