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The Welfare Effects of Environmental Taxation

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Summary

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Keywords: Optimal Environmental Tax, Second-best, Double Dividend, Tax Interaction Effect, Revenue Recycling, Tax Base Effect, Pigouvian Rate, Excess Burden

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Abstract

Recent literature has investigated whether the welfare gains from environmental taxation are larger or smaller in a second-best setting than in a first-best setting. This question has mainly been addressed indirectly, by asking whether the second-best optimal environmental tax is higher or lower than the first-best Pigouvian rate. Even this indirect question, though, has itself been approached indirectly, comparing the second-best optimal environmental tax to a proxy for its first-best value, an expression for marginal social damage (MSD). On closer examination, however, MSD becomes ambiguously defined and variable in a second-best setting, making it an unreliable proxy for the first-best Pigouvian rate. With these concerns in mind, the current analysis reevaluates the central welfare question both directly and indirectly and finds that when compared directly to its first-best Pigouvian value, the second-best optimal environmental tax generally rises with increased revenue requirements. Even in cases where the second-best optimal environmental tax is lower than its first-best value, the welfare gains may be greater than in a first-best setting. These results suggest that the marginal fiscal benefit (revenue recycling effect) exceeds the marginal fiscal cost (tax base effect) over a range of environmental tax rates that, for benchmark models, extends above the first-best Pigouvian rate. Results in the tax interaction literature are fully consistent with these interpretations once the effects of normalizations and numeraires are fully recognized. These findings reinforce the intuition that environmental policy complements rather than competes with the provision of other public goods.

Key words: optimal environmental tax, second-best, double dividend, tax interaction effect, revenue recycling, tax base effect, Pigouvian rate, excess burden

I. Introduction

The central question in the recent environmental tax literature has been whether the welfare gains from environmental taxation in a second-best world are greater or smaller than in a first-best setting. The "double dividend" literature emphasized the larger welfare gains attributable to the efficiency value of pollution tax revenues that could be substituted for preexisting distortionary taxes (e.g., Tullock 1967; Terkla 1984; Lee and Misiolek 1986; Pearce 1991). The subsequent "tax interaction" (TI) literature later rejected the double dividend hypothesis, claiming that environmental taxes "exacerbate rather than alleviate preexisting tax distortions—even if revenues are employed to cut preexisting distortionary taxes" (Bovenberg and de Mooij 1994, p. 1085).[1]

However, this question about the welfare gains from second-best, revenue-neutral environmental taxation has been framed indirectly by asking whether the second-best optimal environmental tax is higher or lower than the first-best Pigouvian rate. Bovenberg and de Mooij, for example, base their conclusion quoted above on showing that "in the presence of preexisting distortionary taxes, the optimal pollution tax typically lies below the first-best Pigouvian tax, which fully internalizes the marginal social damage from pollution." (p. 1085). Fullerton (1997) states the underlying hypothesis succinctly in terms of a test of the "strong form" of the double

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[1] Other contributions include Parry (1995), Bovenberg and Goulder (1997, 2002) and Fullerton (1997). The general finding in the TI literature is that the second-best optimal environmental tax is generally lower than in a first-best setting and, by implication, the welfare gains from environmental taxation are lower than suggested by a first-best analysis. Exceptions to this general findings (i.e., where it is suggested that a double dividend may occur) have been noted in this literature, for example, in cases where labor supply is positively affected by improvements in environmental quality (Schwartz and Repetto 2000; Parry and Bento 2000; Williams 2002; Jaeger 2002). General analytical expressions for second-best optimal taxation were derived by Sandmo (1975), and have been extended for non-linear income taxes and costly abatement technology (Cremer, et al. 1998; Cremer and Gahvari 2001), as well as for heterogeneous households (Boadway and Tremblay 2008). These results are implicit, however, and their precise implications for the welfare effects of environmental taxation remain unclear.

dividend hypothesis, which he defines as the view “that a revenue-neutral switch toward a tax on the dirty good and away from taxation of clean goods can improve environmental quality *and* reduce the overall cost of tax distortions.” Fullerton’s formulates his test for models where only commodities are taxed so that the environmental tax is understood – given other assumptions – to equal the differential between the optimal tax on the dirty good and the optimal tax on clean goods. He continues “[b]y implication, this [double dividend] view might suggest that any additional revenue requirements should be met by raising the tax on the dirty good by more than taxes on clean goods.” (Fullerton 1997, p. 245). Provided some simplifying restrictions are placed on the benchmark models under investigation, this test should be a reliable indicator of the relative welfare changes between second-best and first-best environmental taxation.

On closer examination, however, neither Bovenberg and de Mooij (1994) nor Fullerton (1997) actually perform this test. In the case of Bovenberg and de Mooij, they instead take this indirect test one step further removed from the underlying welfare question as follows: rather than comparing the second-best optimal environmental tax to its first-best Pigouvian value, they observe that the first-best optimal tax equals marginal social damage (MSD^1) at the first-best optimum, define an expression for MSD^2 and evaluate its value in a second-best setting compared to the second-best optimal environmental tax.

If, however, the value of MSD differs in a second-best setting compared to its first-best value, the interpretation of this comparison is ambiguous. Unlike the direct implications of Fullerton’s proposed test, the “twice-removed” indirect tests actually undertaken are problematic – as we shall see below – because in a second-best setting the value of MSD^2 can no longer be relied upon as a proxy for the first-best optimal environmental tax; even its definition is ambiguous.

The current analysis reexamines these issues with a view to clarifying the implications that can legitimately be drawn for the central question that has motivated both the double dividend and tax interaction literatures. Section II presents a "benchmark" model like those used in the tax interaction literature to represent a simple, neutral model for purposes of evaluating these central issues. Section III takes a direct approach to evaluating the welfare gains from environmental taxation. Section IV undertakes the indirect approach proposed by Fullerton. Section V examines the effect the tax normalization on these results, and section VI examines the definition and value of marginal social damage and its numeraire. Section VII discusses the intuitive arguments surrounding this literature, and Section VIII concludes.

II. The Model

The central results and interpretations from the TI literature are understood to relate to certain "benchmark" models where a number of simplifying assumption and restrictions have been made to facilitate the interpretation. Typically these models consist of a population of identical households with preferences such that: a) utility is separable in leisure and environmental quality, b) production is constant-returns to scale with labor as the sole factor of production, c) all goods are average substitutes for leisure, and c) labor supply is upward sloping. These restrictions imply that optimal revenue-raising taxation will involve equal taxes on all commodities so that the difference between the optimal tax on polluting and non-polluting goods will reflect the environmental tax.

The current analysis employs this benchmark structure with a model that includes only two goods, a polluting good *z* and a clean good *x*, that are symmetrical and separable arguments in the utility function, where demands are identical and cross-price effects are zero. Since none of the results in the recent literature depend on the existence of cross-price effects or asymmetries in the consumption sub-utility function, the generality of these interpretations are not affected for current purposes. Full income in our model is a time endowment, *y*, which is allocated between leisure, *l,* and labor supply, *y-l*. Units are chosen for goods and income so that all pre-tax prices equal one. Environmental quality is *E* so that the utility function for *m* identical individuals can be described as

$$u(x, z, E, l) = f(x) + f(z) + h(l) + b(E)$$

with $f'(x), h'(l), f'(z) > 0 > f''(x), f''(z), h''(l),\ \ b'(E) > 0, b''(E) = 0$, and where *E=e(mz), e'(mz)>0, e''(mz) =0.* The household budget constraint is $(1+t_z)z+(1+t_x)x=(y-l)+g$ where *g* is a lump-sum transfer from government. Household maximization yields the indirect utility function for private goods $v(1+t_z, 1+t_x)$, and demand functions $x=s(p_x)$, $z=s(p_z)$, where $s_x<0$.

Labor productivity is unity so that aggregate output is defined as $m(y-l)=m(x+z)$. Transfers of *mg* are financed by distortionary taxes which must satisfy a given revenue requirement, *G*. Thus, the social optimization problem can be stated as

$$\mathcal{L} = mv(1+t_z, 1+t_x, y, g, b(E)) + \mu\left[mt_x x + mt_z z - mg - G\right] + \phi\left[E_0 + e(mx_Z) - E\right]$$

This gives us the first-order conditions for setting taxes t_x and t_z such that

$$\mu_x = \frac{\lambda x}{t_x s_x + x} \qquad (1)$$

$$\mu_z = \frac{\lambda z - mU_E e' s_z}{t_z s_z + z}, \tag{2}$$

where μ is the Lagrange multiplier on the government's budget constraint, reflecting the marginal cost of public funds.

As pointed out by Schöb (1996) and Fullerton (1997), for benchmark models of this kind where the restrictions imply that the optimal revenue-raising taxes are uniform for all goods (ignoring externalities), the optimal environmental tax can be identified as the differential between the optimal tax on the dirty good and the optimal tax on the clean good (rather than the total tax on the polluting good). Alternatively and equivalently one could tax emissions directly. For most of the analysis to follow a commodity tax normalization will be used (where all taxes are on the expenditure side of the budget constraint), as has been the tradition in much of the optimal tax literature (e.g., Ramsey 1927; Sandmo 1975). Later we will indicate how a labor tax normalization (including labor taxes) affects nominal taxes, effective taxes and the numeraire.

III. A Direct Approach to Evaluating Welfare Gains

The question of whether the welfare gains from a revenue-neutral environmental taxation are greater or smaller in a second-best setting than in a first-best setting has important policy implications. Indeed, this question has been reframed as asking whether the collective good of environmental quality is a complement to, or a competitor with, the provision of other public goods. Do higher government revenue requirements strengthen or weaken the case for environmental policy? Or, conversely, does a greater need for environmental policy raise or lower the cost to government of providing other public goods? To evaluate this question as directly as possible, we take two approaches here, one that examines and compares equilibrium conditions in first- and second-best settings and one that compares expressions for marginal welfare changes in first-best and second-best settings.[2]

The first approach considers the first-order conditions for our benchmark model in (1) and (2), recognizing that when $t_z=t_x$, $s(p_x)=s(p_z)$ and $x=z$. This implies that the marginal cost of a tax on z will be lower than the cost of an equal tax on x since (2) has an additional negative term in the numerator (given $e'<0$, $s_z<0$) compared to (1). This term reflects an added benefit or "second dividend" for environmental benefits when taxing z to raise revenue.

Now consider two situations with identical revenue requirements, one with no externality ($e'=0$) referred to as situation A, and the other with an externality ($e'<0$), denoted as situation B. Optimality for each situation implies $\mu^A{}_x=\mu^A{}_z$ and $\mu^B{}_x=\mu^B{}_z$. Beginning at the optimum for situation A, we have $t_z^*=t_x^*$. Those same taxes applied to situation B will mean $\mu^B{}_z<\mu^A{}_z$ and also $\mu^B{}_z<\mu^B{}_x$ based on (1) and (2). To move from this suboptimal tax program (with situation A's optimal taxes applied to situation B) to the optimum for situation B means raising t_z and lowering t_x, which will raise $\mu^B{}_z$ and lower $\mu^B{}_x$ until they are equal at some intermediate level where $\mu^B{}_z=\mu^B{}_x<\mu^A{}_x=\mu^A{}_z$. This result implies that the marginal excess burden of both taxes will be lower at the optimum in situation B than in situation A, implying that the total excess burden is also lower in situation B than in situation A.

From these observations we can see that expressions (1) and (2) represent a ratio of costs

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[2] Efforts to directly evaluate the welfare changes from environmental taxation can be found in the TI literature (e.g., Bovenberg and Goulder 2002), but the welfare expressions are normalized by dividing each term by a numeraire, the private marginal utility of income. These expressions are then manipulated and decomposed into terms which are said to represent environmental benefits, tax interaction effects, etc.. This normalization, however, obscures the interpretation of these expressions because the private marginal utility of income in a second-best setting is a function of the level of revenue-raising taxes, and for a labor tax normalization the units of income are endogenous to these tax rates.

to benefits. The denominators in (1) and (2) represent the incremental revenue (and its public value) – or revenue recycling effect. The first terms in the numerators of (1) and (2) represent the cost of raising revenue imposed on individuals. The ratios will be higher the greater is the "tax base effect" from individuals reducing their labor supply and instead consuming non-taxable leisure. In the case of the dirty good, μ is lowered as a result of the environmental benefits. Second, this apparent complementarity between revenue-raising taxes and environmental taxes is symmetrical: each contributes to the goal of the other, and in so doing generates an additional benefit that would not otherwise occur. Indeed, in a world with abundant externalities deserving taxation, one could in principle fund all government services without distortions.

These observations suggests that from a starting point with equal taxes on *x* an *z*, it will be welfare improving to raise the tax on the dirty good and lower the tax on the clean good. Whether the optimum will occur at a point where the differential between t_z and t_x cannot be ascertained from this thought experiment; It will depend on how the values of μ_x and μ_z change as the two taxes diverge. Thus, in a second-best setting the marginal benefits from the initial introduction of small environmental taxes will exceed those from a comparable Pigouvian analysis, but as the environmental tax is increased the corresponding revenue recycling benefits may decline relative to the tax base effects, giving rise to an optimal environmental tax that is either higher or lower than for a first-best setting. As a result, the total net welfare gain may be greater or smaller than a Pigouvian analysis would suggest.

Our second approach examines the marginal welfare effects of revenue-neutral environmental taxation in more detail. We want to compare the expressions for marginal welfare changes for environmental tax reform with those of a first-best Pigouvian analysis for the specific model reflected in expressions (1) and (2). In both cases our starting point is one with equal taxes on both goods, $t_x = t_z = 0$ in the first-best case, and $t_x = t_z > 0$ in the second-best case. Environmental tax revenues gained when raising t_z are returned lump-sum to the economy via g in the first-best case, and in the second-best case they are used to lower t_x so that a balanced budget is maintained.

The marginal welfare change (dW^1) in a first-best setting for introduction of an environmental tax can be written

$$\frac{dW^1}{dt_z} = mU_E e' s_z - \lambda z + \alpha(t_z s_z + z) \tag{3}$$

where α is the social marginal utility of the lump-sum income, g, given to an individual. This notation distinguishes the value of these lump-sum transfers from μ, the value of Lagrange multiplier when the government budget constraint is binding (and distorting). In the absence of a binding revenue constraint $\mu = \alpha$ and at the first-best optimum $\alpha = \lambda$ as we shall confirm shortly.

With no binding revenue requirement, the social planner's first-order condition can be expressed as

$$\underbrace{mU_E e' s_z}_{environmental\ benefit} = \underbrace{\lambda z}_{\substack{consumer \\ surplus\ loss}} - \underbrace{\alpha\left(t_z s_z + z\right)}_{\substack{lump-sum \\ transfer\ gain}} \tag{4}$$

where the optimum occurs when the marginal environmental gain (left-hand side) is equal to the difference between the marginal consumer surplus lost (the first term on the right-hand side) and the marginal social value of the transfer returned to the economy. The value of the lump-sum transfer, *dg*, is denoted as α. It can be defined generally as

$$\frac{\partial W}{\partial g} \equiv \alpha = \lambda + \mu\left(t_z \frac{\partial z}{\partial g} + t_x \frac{\partial x}{\partial g}\right) + mU_E e'\left(\frac{\partial z}{\partial g}\right). \tag{5}$$

The first two terms of (5) correspond to the social marginal utility of income as recognized by Diamond (1985); the third term augments Diamond's definition to include environmental effects. Given t_x=0 and μ=α, (4) and (5) can be solved simultaneously to obtain $t_z = -mU_E e'/\alpha$. Indeed, substituting $t_z = -mU_E e'/\alpha$ in (5) we can see that the second and third terms cancel so that α=λ. Substituting α=λ into (4) also eliminates terms so that we can confirm that the optimal environmental tax is

$$\tau_z^1 = -mU_E e'/\alpha. \tag{6}$$

where the superscript 1 indicates the first-best optimum.

The use of α as the numeraire is intuitive given that it reflects the value of lump-sum income. But because it is also true at the first-best optimum that the private (λ), social (α), and public sector (μ) marginal utilities of a unit of income are all equal, any one of these could be chosen to define the Pigouvian rate. Indeed, the first-best, first-order condition (4) can be rearranged as

$$\underbrace{mU_E e' s_z}_{\substack{\text{environmental}\\ \text{benefit}}} + \underbrace{(\alpha - \lambda)z}_{\substack{\text{equals}\\ \text{zero}}} = \underbrace{\lambda t_z s_z}_{\text{primary cost}}\ . \tag{7}$$

Recognizing λ=α at the first-best optimum, the second term on the left-hand side equals zero. This manipulation can be interpreted as offsetting the primary cost (lost consumer surplus) with a portion of the third term in expression (4) representing the lump-sum return of revenues to households. This leaves, however, the term on the right-hand side reflecting the distortionary cost that is not offset by the lump-sum return of revenues. This expression also reduces to (6).

In a second-best setting, environmental taxation implies that the revenue changes from increases in t_z will be offset by reductions in t_x. The marginal welfare change for revenue-neutral tax shift, denoted dW^2, can be written as

$$\frac{dW^2}{dt_z} = mU_E e' s_z - \lambda z + \lambda x \frac{(t_z s_z + z)}{(t_x s_x + x)} \qquad (8)$$

or, substituting (1) and rearranging we have at the optimum

$$\frac{dW^2}{dt_z} = mU_E e' s_z - \lambda z + \mu_x (t_z s_z + z) \qquad (9)$$

where μ_x denotes the social marginal utility of public funds when revenue requirement are binding and taxes are distortionary.[3]

Comparing these expressions there are some similarities and differences between the welfare changes in the first-best (3) and second-best (9) settings. First, for the initial increment of environmental taxation, the welfare changes are identical in both settings, and equal to the

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[3] These expressions would include additional terms without the assumption that cross-price effects are zero. The general interpretations, however, are applicable to realistic settings with positive and symmetrical cross-price effects.

environmental benefits reflected in the first term. Note that in (3) with t_z=0, the first term reduces to αz, which in our first-best setting has the same magnitude and opposite sign as $-\lambda z$. Similarly in (8) with $t_z=t_x$, the ratio in the third term reduces to one, and $-\lambda x+\lambda z=0$ given x=z. The initial gain from environmental tax reform is just equal to the reduction in environmental damages, and this is the case in both the first-best setting and the second-best setting.

Differences emerge, however, in how the marginal welfare changes evolve for these two cases as the environmental tax is increased. For situations with positive levels of t_z, $x>z$ so that the ratio in the third term of (8) no longer equals one, and also $-\lambda x+\lambda z\neq 0$. In (3) and (9) we have the first term on the right-hand side equaling the environmental benefit. At the second-best optimum we can set (9) equal to zero and rearrange as

$$mU_E e' s_z + (\mu - \lambda)z = \mu t_z s_z \tag{10}$$

Comparing this second-best relation to its first-best counterpart in (8) is illumination. The first left-hand side terms are equal in both situations, reflecting the environmental benefits from taxing z. The second terms on the left-hand sides of these expressions are very similar, but whereas this term equals zero and drops out at the first-best optimum (the value of revenues collected is equal to its value when returned lump-sum to the economy), it has a positive value in the second-best case given $\mu>\lambda$. This term reflects the “revenue recycling effect” or the incremental revenue valued at the difference between its public and private marginal utility (μ-λ). The term will be larger the greater is the difference between the marginal utility of public funds and the private marginal utility of income.

The right-hand side term in (10) is similar to the corresponding term in (7) except that it is weighted by μ rather than λ. Since μ>λ in the second-best case, this cost is higher in the second-best setting compared to a first-best setting, reflecting both the private distortionary cost and the fiscal or tax base effect. Indeed, we can decompose (10) into two components to get

$$\underbrace{mU_E e' s_z}_{\substack{environmental \\ benefit}} + \underbrace{(\mu - \lambda) z}_{\substack{revenue \\ recycling \\ effect}} = - \underbrace{\lambda t_z s_z}_{primary\ \cos t} + \underbrace{(\lambda - \mu) t_z s_z}_{\substack{tax\ base \\ effect}} . \tag{11}$$

where the first right-hand side term is the primary cost – similar to (7), and the second term represents the fiscal cost or tax base effect – the narrowing of the tax base as increasing t_z reduces consumption of *z*. Overall, then, (11) can be interpreted as setting marginal environmental benefits plus the marginal revenue recycling effect equal to the marginal primary cost plus the marginal tax base effect.[4]

Based on the above, we conclude that in a second-best setting with revenue-raising taxes only, raising the environmental tax incrementally will initially be welfare improving. As the environmental tax is increased further, the revenue recycling benefits (the second term on the left of (10)) will decline and the tax base effects (the second term on the right side of (10)) will increase. The eventual optimal environmental tax will depend on how these changes evolve.

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[4] One caveat is in order, here. The decomposition of the right-hand side term from (10) into the two terms in (11) could have been accomplished by introducing α in both terms rather than λ. This would alter the relative magnitudes of the two terms but leave their sum unchanged. Using λ gives the appearance that the primary cost term is the same in (10) as in (7), but this may be misleading since λ is lower and t_z is higher in the second-best setting the higher is the level of taxes (more on this below). Using α to decompose the two terms would allocate the cost between these two components differently (and potentially with little change in value compared to the first-best setting). However, since neither the social nor the private marginal utility will have precisely the same value in a second-best setting as in a first-best setting, the preferred or most intuitive choice for the current interpretation is debatable. What is certain is that the sum of these two terms is greater than the right-hand side term in (8) because μ>α>λ, so that the total cost (primary and tax base) is higher than in a first-best setting.

Whether the optimal environmental tax will be higher or lower than in the first-best case is ambiguous at this point. But even if the second-best environmental tax is lower than in first-best, it does not necessarily follow that the welfare gains in a second-best setting are also lower.

These relationships are illustrated in Figures 1A and 1B. In Figure 1A, a first-best analysis would involve a “primary” trade-off involving environmental marginal benefits (MB_E) and marginal primary costs (MC), giving rise to a first-best optimum at Q^{*1} with net benefits equaling area A. In a second-best setting there are also secondary fiscal marginal benefits (revenue recycling gains MB_{RR} added in Figure 1 to MB_E) and marginal costs (tax base effects, MC_{TB}, subtracted in Figure 1 from MB_{RR}+MB_E). As abatement increases in response to the environmental tax the secondary marginal benefits (revenue recycling, MB_{RR}) are traded-off against secondary marginal costs (tax base effects, MC_{TB}). The optimum occurs when the sum of primary and secondary marginal benefits equal the sum of primary and secondary marginal costs – or when $MB_E+MB_{RR}-MC_{TB}=MC$. In Figure 1A this occurs where the second-best optimum, Q^{*2} is higher than Q^{*1}, and with welfare gains equal to areas A and B.

Other outcomes are possible such as the one depicted in Figure 1B where Q^{*2} is below Q^{*1}. In this case the marginal net benefits were positive at low environmental taxes, but as the environmental tax is increased the tax base effect grows larger relative to the revenue recycling effect, causing the optimum to occur below Q^{*1}. In this case the welfare gains are equal to triangles A+B-C, which may be larger or smaller than for the first-best analysis depending on the relative sizes of B and C.

Concluding that the second-best optimal pollution tax is below the first-best Pigouvian rate is not sufficient evidence to infer that the welfare gains from environmental taxation are less than in a first-best case. Indeed, all of the welfare changes associated with second-best

Figure 1A. Marginal Costs and Benefits for Second-Best Environmental Taxation

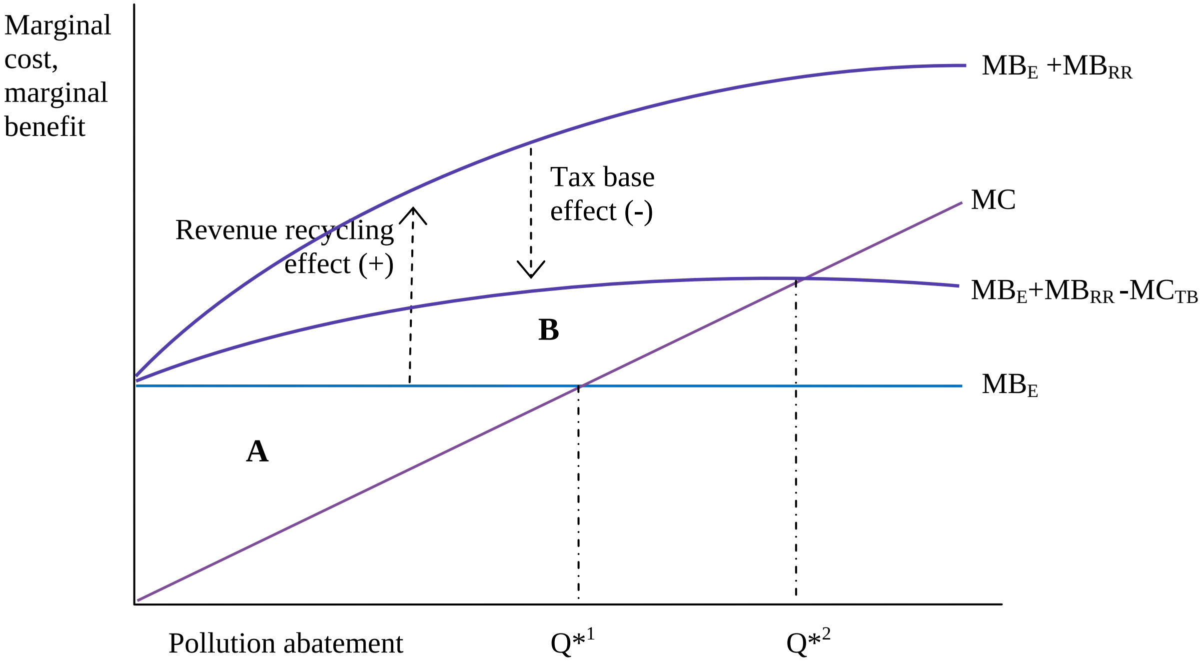
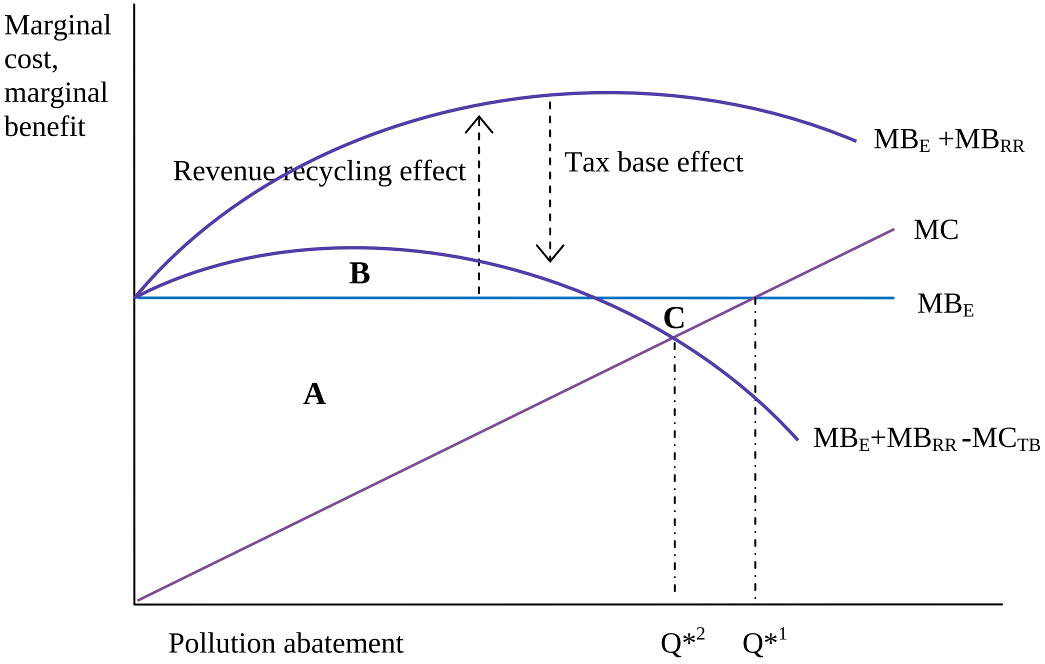


Figure 1B. Marginal Costs and Benefits for Second-Best Environmental Taxation



environmental taxation occur in expressions (1) and (2), and also (7) and (11). The costs that do appear are the well-known Ramsey tax base effects present for taxes on all commodities. The first-order conditions for commodities are similar to those we would see for direct taxation on emissions. And the situation depicted in Figure 1A is consistent with our analysis suggesting that environmental taxation and the provision of other public goods are complements rather than competitors.

IV. The Second-Best Optimal Environmental Tax Compared to its First-Best Value

Here we carry out the test proposed by Fullerton (1997) to evaluate whether the optimal environmental tax increases or decreases as revenue requirements increase beyond levels that can be satisfied with revenues from a first-best Pigouvian tax. If the optimal tax on the dirty good increases faster than the optimal tax on the clean good, the environmental tax (differential), τ, is increasing along the continuum of rising government revenue requirements.[5] And by implication, the welfare gains from environmental taxation would affirm Fullerton's "strong form" of the double dividend hypothesis, improving the environment and reducing the overall cost of tax distortions.

Although Sandmo's (1975) second-best optimal tax expressions cannot be interpreted directly by inspection for our purposes, we can interpret them by making use of the assumptions for our baseline model. Sandmo's expressions can be written transparently with current notation for goods x and z as

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[5] Given our assumption of linear environmental damages, the utility measure of marginal damages is unchanged across all allocations.

$$\frac{t_x}{(1+t_x)} = \frac{(\mu-\lambda)}{\mu}R$$

and

$$\frac{t_z}{(1+t_z)} = \frac{(\mu-\lambda)}{\mu}R + \frac{mU_E e'}{\mu(1+t_z)} \qquad (12)$$

where R is the Ramsey term. [6]

For clarity it's important to note that Sandmo's original notation for the expression in (12) has at times created confusion in the literature about the separability of terms and the transparency of their interpretation. The second term on the right-hand side of (12) cannot be evaluated as an additive component of the nominal tax on the dirty good, $t_{z,}$ because it appears in both numerator and denominator of the left-hand side. Changes in the value of the second term on the right will alter t_z in non-additive ways.[7]

Sandmo's expressions can, however, be rearranged to produce a separable expression for

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[6] The Ramsey term, *R* refers to a term involving elements of the matrix of uncompensated demands of taxed goods, **S**. In a model with *n* goods, defining S_{ij} as the cofactor of the element in the ith row and jth column of **S**, and with **Š** being the determinant of **S**, we have $R \equiv \sum_{i=1}^{n} x_i S_{ij} \Big/ p_j \check{S}$. This term reflects the revenue generating potential for a marginal change in the tax on x_i due to the direct and indirect effects on consumption of all goods.

[7] Sandmo defines tax rates as the tax-inclusive rate or $\theta_k = t_k/(1+t_k)$ rather than as the nominal tax. Nevertheless, Sandmo's result in (12) has been mistakenly represented as $t_D = \left(1-\frac{1}{\eta}\right)R + \frac{1}{\eta}\tau$ by Fullerton and similarly by Auerbach and Hines where τ is the Pigouvian rate, η is the marginal cost of public funds (μ/λ), and R is the Ramsey term. Fullerton's interpretation is that for clean goods the second term on the right-hand side is zero, and so the differential between the optimal tax on a dirty good and a clean good equals the second term. He concludes from this that "with distorting taxes in the economy, a marginal dollar of revenue has a social cost that is more than a dollar (η >1) . Thus, the environmental component (τ/η) is less than the Pigovian rate (τ).(p. 248)" Auerbach and Hines similarly conclude that the tax on the dirty good will "equal the sum of the 'optimal' tax that ignores the externality… plus a term that reflects the cost of the externality. This second term equals the corrective Pigouvian tax … divided by the [marginal cost of public funds], μ/λ.(p. 1388)" Correct interpretation of Sandmo's notation does not support these conclusions.

the nominal environmental tax. Multiplying both sides by (1+t_z) we have

$$t_x = \frac{(\mu - \lambda)}{\mu} R(1 + t_x)$$

and

$$t_z = \frac{\mu - \lambda}{\mu} R(1 + t_z) + \frac{mU_E e'}{\mu}$$

Comparable expressions to this are found in Boadway and Tremblay (2008). These can be rearranged as

$$t_z - t_z \frac{\mu - \lambda}{\mu} R = \frac{\mu - \lambda}{\mu} R + \frac{mU_E e'}{\mu}$$

and as

$$t_z = \frac{\frac{\mu - \lambda}{\mu} R}{\left[1 - \frac{\mu - \lambda}{\mu} R\right]} + \frac{\frac{mU_E e'}{\mu}}{\left[1 - \frac{\mu - \lambda}{\mu} R\right]} \tag{13}$$

Defining *t* as the common value of the optimal tax on clean goods (dropping the subscript), and with our maintained assumption symmetric demands for both polluting and non-polluting goods (equal Ramsey terms) we can rearrange (13) to express the Ramsey term as

$$R = \frac{\frac{t}{1 + t}}{\frac{\mu - \lambda}{\mu}} \tag{14}$$

Substituting (14) into (13) and simplifying we have

$$t_z = t + \frac{(1+t)}{\mu} mU_E e' ,$$

and thus we can express the environmental tax τ^c ($= t_z - t$, where the superscript indicates a commodity tax normalization, discussed below) as

$$\tau^c = \frac{(1+t)}{\mu} mU_E e' . \tag{15}$$

From this expression we can see that the change in the environmental tax with increased revenue requirements is ambiguous. Increased revenue requirements will increase t in the numerator of (15) but we also expect μ to rise (for realistic models where labor supply is upward-sloping so that taxes are distortionary). The question of whether the environmental tax rises or falls with increased revenue requirements, therefore, will depend on how $1+t$ rises relative to μ.

The expression in (15) can be used to evaluate the relationship between the optimal environmental tax in a first-best setting, τ^1, and in a second-best setting, τ^2. At the first-best optimum we know that $t=0$, and $\mu^1=\lambda$. In the second-best setting we have $\tau^2 = (1+t)mU_E e'/\mu^2$, so that the ratio $\tau^{2/}\tau^1$ can be written as $(1+t)\ \mu^1/\mu^2$. We can express the ratio of the social value of public funds between second- and first-best settings as $\mu^2/\mu^1=1+MEB$ where MEB is the marginal excess burden of the tax (expressed in dollars). Combining these expressions, and assuming constant marginal damages, we have

$$\frac{\tau^2}{\tau^1} = \frac{(1+t)}{1+MEB} \tag{16}$$

We now have an expression of the relationship between the first-best and second-best environmental tax, and we see that it may rise, or fall, depending on whether (1+t) rises more or less than (1+MEB) as revenue requirements increase above the first-best starting point.

This relationship is implicit in Browning's (1987) seminal analysis of the marginal welfare cost of taxation for the U.S. economy. For his primary "polar case" where marginal government spending provides benefits that return taxpayers to their initial utility levels (i.e., prior to the tax and expenditure changes), and assuming incremental tax revenue is derived from proportional changes in all tax rates, Browning's expression for the marginal excess burden (MEB) per dollar of revenue for an income tax normalization can be written as

$$MEB = \frac{\left[\frac{t_L + 0.5dt_L}{1 - t_L}\right]\eta}{1 - \left[\frac{t_L + dt_L}{1 - t_L}\right]\eta},$$

where η is the compensated labor supply elasticity. For the commodity tax normalization, the tax on each commodity satisfies t_L=(t/1+t). With a common tax and identical demands we can interpret this as a composite of many clean goods so that the equivalent expression is

$$MEB = \eta\left[\frac{\left(\frac{t}{1+t}\right) + 0.5d\left(\frac{t}{1+t}\right)}{1 - \left(\frac{t}{1+t}\right)}\right]\left(1 - \left[\frac{\left(\frac{t}{1+t}\right) + d\left(\frac{t}{1+t}\right)}{1 - \left(\frac{t}{1+t}\right)}\right]\eta\right)^{-1} \tag{17}$$

Combining (17) with (16) we can express the ratio of the second-best environmental tax to the first-best Pigouvian tax as

$$\frac{\tau^2}{\tau^1} = (1+t)\left(1-\left[\frac{\left(\frac{t}{1+t}\right)+d\left(\frac{t}{1+t}\right)}{1-\left(\frac{t}{1+t}\right)}\right]\eta\right)\left(1-\left[\frac{0.5d\left(\frac{t}{1+t}\right)}{1-\left(\frac{t}{1+t}\right)}\right]\eta\right)^{-1} \tag{18}$$

For a range of key parameter values and assumptions, Browning has presented estimates of MEB. These estimates in turn permit us to compute the optimal environmental tax as a percent of its first-best Pigouvian rate for a commodity tax normalization, which will allow us to perform Fullerton’s test using (18). Results are shown in Table 1, indicating that the second-best optimal environmental tax exceeds its first-best Pigouvian value for all but a few combinations of extreme parameter values considered by Browning. For central parameter values the optimal environmental tax is estimated to be 25% – 40% above its first-best value.

The expressions above can be used to estimate a continuous relationship between the optimal environmental tax differential and revenue requirements for specific central parameters and assuming a constant labor supply elasticity. These relationships are illustrated in Figure 2 as a percent of the first-best Pigouvian rate, and for each of three compensated labor supply elasticities, 0.2, 0.3, and 0.4. These estimates indicate that the optimal environmental tax will rise above its first-best level and remain there for the tax rates and labor supply elasticities relevant to the U.S. economy. Only at commodity tax rates of 150% (equivalent to a 60 percent income tax) does the optimal environmental tax begin to drop below its first-best level due to a shift onto the downward slope of the revenue or “Laffer” curve. For the central estimates used in much of the literature (a 40% income tax and η=0.3), the optimal environmental tax is estimated from (18) to be 33 percent above its first-best level.

An obvious alternative approach to test whether the optimal environmental tax rises or

Table 1. Optimal environmental tax as a percent of the first-best Pigouvian rate

	Income tax rate:	0.38			0.43			0.48		
	Labor supply elasticity:	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
	dm/dt									
Earnings constant	0.8	147%	140%	135%	156%	148%	141%	167%	157%	148%
	1.0	143%	136%	129%	152%	143%	134%	162%	150%	140%
	1.39	138%	128%	120%	145%	133%	123%	153%	138%	127%
	2	129%	117%	108%	134%	120%	109%	140%	123%	110%
Earnings decline	0.8	145%	137%	129%	154%	143%	133%	164%	149%	135%
	1.0	141%	131%	121%	149%	135%	122%	156%	138%	120%
	1.39	133%	119%	105%	138%	119%	101%	142%	117%	92%
	2	121%	101%	81%	122%	95%	68%	120%	84%	48%

Based on Browning (1987).

falls with increased revenue requirements is with a numerical general equilibrium model calibrated consistent with these same benchmark assumptions. Indeed, such models can be found in the TI literature, and in one well-known example (Bovenberg and Goulder 1996) optimal carbon tax results are provided for a range of income tax levels in a model where marginal damages are assumed to be $75/ton. These results can be renormalized for our commodity tax normalization so that the optimal carbon tax reflects the differential between the optimal taxes on polluting and clean goods. These optimal carbon taxes are shown in Figure 3, where they rise from a first-best value of $75/ton to $100/ton when tax rates are assumed in the model to be similar to those existing in the U.S. economy (equivalent to a 40% income tax).[8] These numerical results conform very closely to those presented in Figure 2 where the optimal environmental tax rises about 33% above its first-best value for a 40% labor tax rate. By implication these results suggest that the welfare gains from environmental taxation in a second-best setting are larger than in the first-best setting, consistent with areas A+B in Figure 1A.

The analysis thus far supports the notion that the welfare gains from environmental taxation will generally be higher in a second-best setting than in a first-best setting because, over a range of incremental increases in the environmental tax, the marginal fiscal benefits (revenue recycling effect) will be larger than the marginal fiscal costs (tax base effect). For benchmark models calibrated to represent the U.S. economy, the optimal environmental tax is estimated here to be 25% - 40% higher than the first-best Pigouvian rate.

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[8] Similar results are found for a numerical general-equilibrium model in which climate change damages affect productivity rather than amenities. Jaeger (2002) finds the optimal (effective) carbon tax to be 53% above its first-best level for tax rates equivalent to a 40% income tax. Jaeger's estimates are higher than the 33% increase implicit in Bovenberg and Goulder's analysis because the climate externality is assumed to affect productivity (e.g., climate change is assumed to reduce productivity in sectors such as agriculture and forestry, and to reduce productivity of fixed assets). Introduction of the carbon tax lowers emissions which raises productivity and output, which in turn broadens the tax base allowing the overall level of taxes to be slightly lowered. In this way Jaeger's model differs from the current benchmark models.

Figure 2. Optimal environmental tax with varying revenue requirements and constant labor supply elasticities: commodity tax normalization

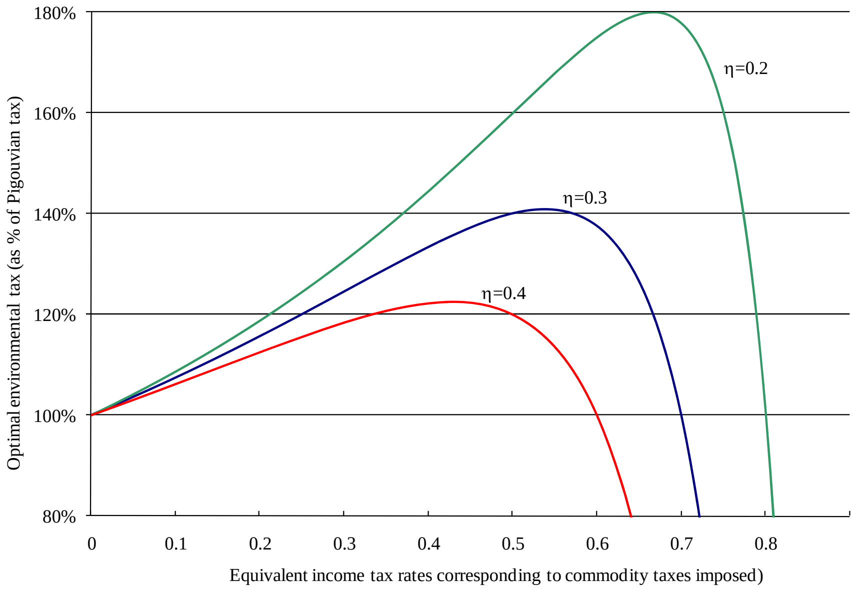
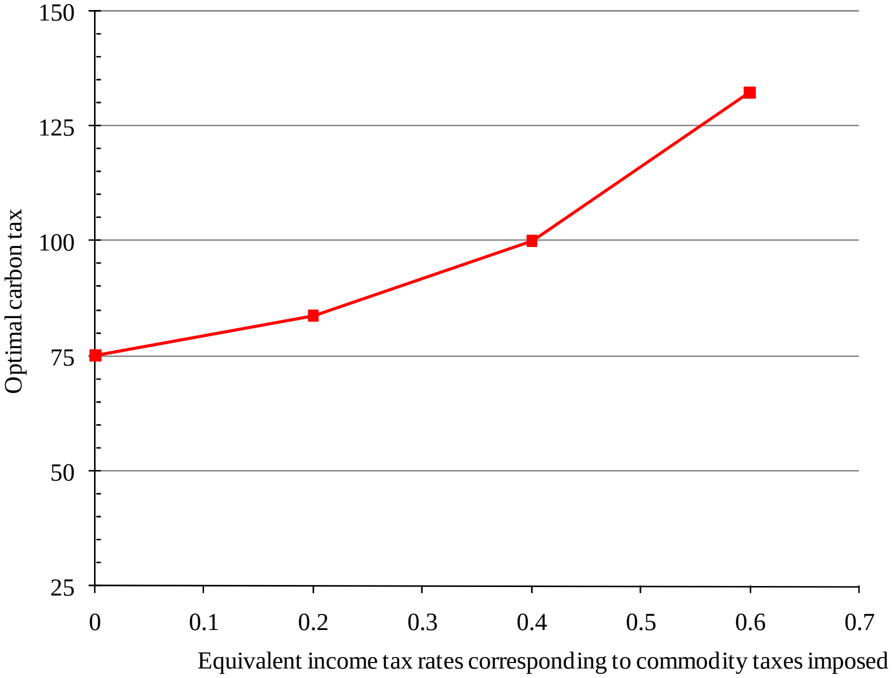


Figure 3. The Optimal Carbon Tax Under Varying Revenue Requirements: Commodity Tax Normalization



Source: Bovenberg and Goulder (1996, p. 994).

V. Tax Normalizations and their Effects

How are these results affected by the use of a different tax normalization? In terms of welfare, resource allocation, or any other real variables, changing the tax normalization are understood to have no effect at all. In terms of appearances, nominal values, and the units of income, a change in tax normalization alters these results across different revenue requirements in ways that have obscured their meaning and produced misleading interpretations.

A labor tax normalization involves introducing revenue-raising taxes on the income side of the budget constraint rather than on the expenditure side. This has one advantage, but also distinct disadvantages. The advantage is that income taxes are present in the U.S. economy and many other countries, and so the actual implementation of optimal environmental taxes in these contexts would need to take account of these tax structures. Income taxes also affect our estimates of environmental damages (depending on the methods used) and the nominal value of the optimal environmental tax.

Our main interest here, however, is not tax implementation but answering a theoretical question about the welfare gains from environmental taxation. And in that regard, the income tax normalization has a distinct disadvantage. When taxes are introduced on both sides of the budget constraint there is a direct compounding effect, or “double taxation” involving these direct and indirect taxes. The specific implications are as follows:

Given the symmetry imposed for the benchmark models, the optimal revenue raising tax program will require uniform taxes on all expenditures or, equivalently, a tax on labor income. In a perfectly competitive economy, a labor tax t_L will be equivalent to a uniform commodity tax t

so long as $1-t_L=1/(1+t)$. This is understood to be a nominal phenomenon with no effect on any real variable, or on the distortions at all margins (Fullerton 1997; Schöb 1996). The model's household budget constraint under a commodity tax normalization:

$$(y-l) = (1+t)x + (1+t+\tau)z. \tag{19}$$

If the revenue raising tax, t, is zero, then the only tax is the environmental tax τ^c. With a positive, uniform revenue-raising tax, t, the environmental tax τ will be added so that the total tax on z is $t+\tau^c$. In the case of a labor tax normalization, a tax program equivalent to (19) can be implemented where a labor tax t_L replaces t where $1-t_L=1/(1+t)$. Algebraically both sides of (19) are multiplied by $(1-t_L)$ and $1-t_L=1/(1+t)$ is substituted where convenient. The resulting labor tax normalization can be represented in terms of τ from (19) included as

$$(y-l)(1-t_L) = x + (1+(1-t_L)\,\tau^c)z \tag{20}$$

With the labor tax normalization the (nominal) environmental tax is still considered to be the differential between the tax on z and the (zero) tax on x. Its value differs between the two normalizations in (19) and (20); the difference being a function of the revenue raising tax level such that

$$\tau^L=\tau^c\,(1-t_L). \tag{21}$$

It follows that $\tau^L<\tau^c$ and that the difference between the two is an increasing function of the tax rate.[9] The implication is that when starting from a first-best optimum with a Pigouvian tax, the introduction of revenue-raising taxes will cause adjustments in the optimal environmental tax (differential), and these adjustments will differ for these two tax normalizations. Indeed, for the results presented above they trend in opposite directions. Since differences across these two normalizations involve only nominal phenomenon with no effect on any real variable, the real disincentives facing polluters are the same for both normalizations, as are the welfare effects from environmental taxation.

A useful distinction can be made between the "nominal environmental tax" and the "effective environmental tax." The nominal environmental tax in each case equals τ^c for the commodity tax normalization and τ^L for the labor tax normalization. It is simply the differential between the ad valorem tax on z and on x. The effective environmental tax is defined to account for the compounding effects or double taxation if there are direct and indirect taxes on both the income and expenditure sides of the budget constraint. The effective environmental tax can be understood to be asking: How much revenue is generated from the presence of the pollution tax when holding consumption constant?

For the commodity-tax normalization, the nominal and effective taxes are the same: each unit of z consumed will generate an additional τ in revenue compared to when $\tau=0$. For an income tax normalization with a labor tax t_L and an environmental tax τ^L, a household will pay a pollution tax τ^L compared to the case where $\tau^L=0$. To finance τ^L, however, the household will need to increase labor supply by $\tau^L/(1-t_L)$. This represents the additional tax revenue resulting from the pollution tax, and can also be expressed as $\tau^L(1+t)$. From the identities for the two normalizations we know that $\tau^L(1+t)= \tau^L/(1-t_L)=\tau$. Thus, the effective environmental tax for the

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[9] The observation that the optimal environmental tax differential varies depending on the tax normalization is recognized by Auerbach and Hines (2002) and is acknowledged by Williams (2001).

income tax normalization is equal to the nominal (and effective) tax under the commodity tax normalization. In one case there is only a direct tax on pollution that is relevant; in the other case, the tax has been separated into a direct and indirect component.[10] The commodity tax normalization has an advantage of avoiding confusion since the nominal and effective environmental taxes are the same.

Given these equivalencies across tax normalizations, Sandmo's optimal tax expression in (15) above can be transformed for an income tax normalization (with superscript *L*) by substituting (21) to get

$$\tau^L = \frac{mU_E e'}{\mu} . \tag{22}$$

Indeed this is equivalent to the optimal environmental tax expression derived by Bovenberg and Goulder (1996, p. 987).[11]

From (22) we see that for benchmark models involving a labor tax normalization, and assuming that μ increases with rising revenue requirements, the nominal environmental tax will indeed decline below its first-best Pigouvian value in a second-best setting. This differs from the

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[10] The definitions of nominal and effective taxes are, of course, distinct from their marginal revenue which depends on the responsiveness of consumers to price changes.

[11] This formulation of the tax differential between the optimal tax on the dirty good and the optimal tax on the clean good implicitly defines it as the environmental component (similar to Fullerton (1997), Schöb (1996), and others). One may also consider a portion of this differential to be a "Ramsey portion" of the environmental tax (for example, the portion of the differential which exceeds the first-best Pigouvian tax). The differential can be represented, or thought of, either way, both intuitively and algebraically. The question being addressed here, however, makes no distinction in that regard. We are looking only to see whether the entire differential rises or falls with an increase in revenue requirements.

commodity tax normalization in (15) and estimated for a range of parameters in Table 1. Indeed, the same Table 1 results are shown in Table 2 to reflect the nominal environmental taxes for a labor tax normalization. These results confirm that while the effective tax will rise above its first-best value, the nominal environmental tax will drop below the first-best Pigouvian tax in a model with a labor tax normalization. Each of the *nominal* tax changes indicated in Table 2 when going from a first-best optimum to a second-best optimum correspond to the *effective* tax changes shown in Table 1.

As a practical matter when measuring environmental damages or estimating what the corresponding nominal tax rate should be, an income tax normalization raises issues that have not received much attention in the literature. For example, if marginal damages are estimated on the basis of individuals' after-tax income, these estimates may understate the social damages to the extent that they exclude lost government revenue or overall effects on GDP (for example in the case of reduced agricultural yields or lost labor productivity). Measurement issues of this kind occur for health impacts similar to on-the-job risks to life and health, where estimates of individual willingness-to-pay to reduce risks will correspond to their after-tax wages rather than their gross wages (Viscusi 1993). Marginal social damages, however, will include the lost gross income including both the public value of reduced revenues and the private value of foregone after-tax wages. Measurement issues of this kind can be addressed by noting these differences and the gross wage impacts corresponding to damages that have been measured in after-tax income units. Damages based on reductions in GDP due to air pollution or climate change, for

Table 2. Optimal environmental tax as a percent of Pigouvian rate for a labor tax normalization

	Income tax rate:	0.38			0.43			0.48		
	Labor supply elasticity:	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
	dm/dt									
Earnings constant	0.8	91%	87%	83%	89%	85%	80%	87%	82%	77%
	1.0	89%	84%	80%	87%	81%	77%	84%	78%	73%
	1.39	85%	79%	74%	83%	76%	70%	79%	72%	66%
	2	80%	73%	67%	77%	69%	62%	73%	64%	57%
Earnings decline	0.8	90%	85%	80%	88%	82%	76%	85%	78%	70%
	1.0	88%	81%	75%	85%	77%	69%	81%	72%	63%
	1.39	83%	74%	65%	79%	68%	57%	74%	61%	48%
	2	75%	63%	50%	69%	54%	39%	63%	44%	25%

Based on Browning (1987).

example, will correspond to gross income units, and include social losses not included in individuals' willingness-to-pay.[12]

VI. Marginal Social Damage and its Numeraire

Instead of comparing the second-best optimal environmental tax to its first-best counterpart, can we compare it to MSD^2 and still make the same inferences about the welfare gains from environmental taxation? The short answer is no. The second-best optimal tax can defined using one of three possible numeraires representing the social, private or public sector marginal utility of income. From (15) these can be expressed in terms of MSD^2, but where any one of three definitions of MSD^2 (in brackets) is used:

$$\tau^c = (1+t)\frac{\alpha}{\mu}\left[\frac{mU_E e'}{\alpha}\right] = (1+t)\frac{\lambda}{\mu}\left[\frac{mU_E e'}{\lambda}\right] = (1+t)\left[\frac{mU_E e'}{\mu}\right] \tag{23}$$

Similarly for a labor tax normalization, these same three expressions become:

$$\tau^L = \frac{\alpha}{\mu}\left[\frac{mU_E e'}{\alpha}\right] = \frac{\lambda}{\mu}\left[\frac{mU_E e'}{\lambda}\right] = \frac{mU_E e'}{\mu} \tag{24}$$

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[12] Alternatively, rather than raising the estimates of marginal environmental damage to account for the lost revenues associated with losses in after-tax income, one could interpret the difference between net and gross income effects from environmental improvement (in response to a pollution tax) as a "benefit-side tax interaction effect," as Williams (2002) has done.

The indirect test of the double dividend proposition as proposed by Fullerton is whether $\tau^2 > \tau^1$. Instead of comparing τ^2 to the left-hand side of (6), the TI literature has instead compared τ^2 to the right-hand side of (6), or MSD. This substitution of MSD for τ^1 would be satisfactory and consistent with the approach taken above if MSD were a reliable proxy for τ^1, stable and unaffected by the introduction of revenue-raising taxes. Given the assumption that $e''=0$ the numerator of MSD is unaffected by changes in resource allocation. The denominator, however, is the numeraire unit of value and it is affected by revenue-raising taxes; indeed in the presence of revenue-raising taxes the definition of the numeraire becomes ambiguous, as described in (23) and (24) based on numeraires reflecting the private, social, and public sector value of income. Some of these versions of MSD have values greater than τ^2, others lower (see Jaeger 2004). As a result, the test $\tau^2 >< MSD$ is not equivalent to the test $\tau^2 >< \tau^1$ if $MSD \neq \tau^1$.

The practice in most of the TI literature has been to utilize the private marginal utility of income, λ, as the numeraire rather than the social marginal utility of income, α. Others have emphasized expressions involving the marginal rate of substitution between environmental quality and public goods, μ (van der Ploeg and Bovenberg 1994; Orosel and Schöb 1996). In principle, any one of these could be used to set the optimal environmental tax. For two of the three versions of MSD with a commodity tax normalization, the optimal environmental tax would be higher; for two of the three measures under a labor tax normalization the optimal environmental tax would be lower than MSD. For all three expressions (corresponding to a given normalization), the only difference is how MSD is defined: the left-hand side is unaffected. Can any of these be said to represent *the* valid test of whether the welfare gains from environmental taxation are larger or smaller in a second-best setting than in a first-best case? There does not appear to be a straightforward way to prove the superiority or legitimacy of one numeraire over others for our test. However, a strong case can be made for using the social marginal utility of income because it is the most stable across revenue requirements, and it represents a consistent and intuitive concept: the value to society of giving an individual an extra unit of income, taking account of the incremental revenue it generates.[13]

It is worth emphasizing that the choice of numeraire has no effect on the optimal environmental tax; it has no effect on whether the second-best optimal environmental tax is higher or lower than its first-best counterpart; and it has no effect on the welfare gains from environmental taxation in a second-best setting, or how they compare to a first-best setting. The choice of numeraire only affects appearances, whether the second-best optimal environmental tax appears to be higher or lower than one of six possible expressions for MSD.

One expression for MSD among the six in (23) and (24) is problematic not just because its value is endogenous to the revenue requirement, but because its value depends on the normalization. This expression involves the use of λ as the numeraire under a labor tax normalization; the version used in most of the T I literature. For a labor tax normalization and when using the private marginal utility of income as the numeraire, not only does the value of income change with the level of revenue-raising taxes but the units change as well. This endogenous relationship between the labor tax and the income unit may not be obvious in analytical models where units have been chosen so that pre-tax prices equal one. In the interest

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[13] The choice of which marginal utility of income to use as the numeraire is analogous to choosing the discount rate in multi-period models with capital and taxes on investment income. The discount rate to use for public investments is understood to be the shadow price of capital, and for some common classes of models this rate will lie between the pre-tax rate of return and the after-tax rate of return (Sandmo and Dreze 1971). Sandmo and Dreze find that the social discount rate will be a weighted average of the pre- and after-tax rate of interest, similar to Diamond’s definition of the social marginal utility of labor income. Yet in contrast to the current literature which has unquestioningly relied on the private value of labor income (see, for example, Howarth 2005), there is widespread recognition in the case of capital that its social value will diverge from its private value, and that the former is the relevant measure for evaluating social optimality.

of clarity, let's compare the budget constraints for a commodity tax normalization in (19) and the labor tax normalization in (20), where income is on the left and expenditures on the right-hand side. A one-unit increase in income implies increasing the value of the left-hand side by one unit for both budget constraints. In the absence of any revenue-raising taxes, and a wage of $1/hour, this would mean an increase in the time endowment of one hour for both. If, however, we introduce a 67% commodity tax in (19) and an equivalent labor tax of 0.4 in (20), the units are no longer the same for these two budget constraints. A one-unit increase in income in (19) still corresponds to an hour of time, but in the case of the labor tax normalization a one-unit increase in income corresponds to an increase in the time endowment of 1.67 hours of additional time. The private marginal value of income, λ, in this case, is the value of an incremental unit of net income. With a 40% income tax rate, the marginal value of income reflects the marginal utility to an individual who is indifferent between a choice of an additional 1.67 units of leisure or one additional unit of either x or z. If this same situation is presented with a commodity tax normalization, the value of λ instead represents the marginal utility to an individual who is indifferent in a choice between 1 unit of leisure or 0.6 additional units of either x or z. An equilibrium situation in our models with either of these tax normalizations will be equivalent in terms of the allocation of resources, welfare, and tax revenues, but the private marginal utility of income will differ because the units are different. They correspond to different quantities of additional income (time in this case), and so the use of these different normalizations does have real implications for the magnitudes of key parameters for the current analysis – the nominal environmental tax and the measure of a unit of income – and this further complicates their comparability and interpretations.

VII. Intuitive Arguments

The intuition suggested in the TI literature includes three related components: 1) that environmental taxes are narrower taxes than employment taxes, so that revenue-neutral environmental tax reform will narrow rather than broaden the tax base; 2) that there are gross costs associated with environmental taxes that are large relative to the revenue-recycling gains, and as a result the costs of environmental policy increase in a second-best setting relative to a first-best setting; and 3) that the collective (or public) good of environmental quality competes with other public goods, so that the marginal cost of environmental policy rises with the marginal cost of public funds. Let's examine each of these.

The first claim is that "… environmental taxes generally are more narrow than factor taxes; hence, they are less efficient mechanisms for raising revenue … than factor taxes are" (Bovenberg and Goulder 2002, p. 1538). This argument appeals to first principles from optimal tax theory that broader tax programs generally have lower distortionary costs than narrow ones. However, because in this situation a direct tax is being compared to an indirect tax reflecting different normalizations, the applicability of the principle is unclear. To see the logic of the argument more transparently we can reframe the situation as an equivalent one with uniform taxes on all commodities representing the revenue-raising taxes rather than a labor tax. In this setting, environmental taxation would involve raising the tax on pollution and using the revenues to finance a reduction in the uniform revenue-raising taxes on all other goods. The total tax burden on consumers would be unchanged.

From this vantage point of a commodity tax normalization, the TI intuition is less apparent. Environmental taxation adds a tax to a previously untaxed "good" (environmental waste disposal services) while at the same time allowing commodity tax rates to be slightly lowered. We can see this most easily if we assume that emissions are taxed directly and separately from taxes on all other commodities. In that light, adding the environmental tax appears to broaden the tax base (by adding a new tax on emissions), while at the same time allowing the revenue-raising tax rates on all other goods to be lowered. How does this amount to narrowing the tax program? Indeed, starting from a first-best optimum where all externalities are taxed at their Pigouvian rates, intuition suggests that a broad-based revenue-raising tax program should add Ramsey tax premiums to all expenditures including adding a Ramsey premium to the cost of polluting.

The second intuitive argument in the TI literature suggests that the “gross costs” associated with environmental taxes are large relative to the revenue recycling benefits: “Environmental taxes introduce gross distortions by reducing the labor supply. The larger the pre-existing labor taxes, the greater the wedge between the private and social value of labor, and thus the larger the gross cost associated with a given reduction in labor supply. Thus, higher pre-existing labor tax rates imply larger costs from given environmental tax reform”(Bovenberg and Goulder 2002).

Once again the use of a labor tax normalization may obscure this intuitive argument. We again reframe this argument in terms of a model where the renormalized tax program includes uniform revenue-raising taxes on all goods rather than an income tax. From this perspective we can see that the idea of how a tax will discourage labor supply and narrow (slightly) the tax base is true for taxes on all goods, not just environmental taxes. Indeed this phenomenon is explicit in (11) and applies to non-polluting goods for which the first term will equal zero. It will certainly be true that the larger the pre-existing (commodity) taxes, the greater the distortionary effects for further tax increases (i.e., the right-hand side of (11)), but this observation applies to all goods and is central to setting optimal Ramsey taxes. In the case of pollution, or any other good, higher revenue requirements and tax rates make the distortionary tax base effects larger due to the size of (λ-μ), but the positive revenue recycling effects will be larger as well as they are also weighted by (λ-μ). Comparing the revenue recycling effect and the tax base effect in (11), there does not appear to be theoretical evidence to supporting "the dominance of the tax-interaction effect over the revenue-recycling effect" (Bovenberg and Goulder 2002, p. 1538).

Nevertheless, the insight that there are both secondary (fiscal) benefits and costs to be traded-off is an important contribution of the TI literature. Indeed, early contributions to the "double dividend" literature considered only the secondary benefits from revenue recycling and ignored the secondary costs, resulting in greatly overstated optimal tax rates and associated welfare gains from environmental tax reform (e.g., Nordhaus 1993; Jaeger 1995). The TI literature recognized that, as with any revenue-raising tax on any commodity, there is both a revenue-generating benefit and a distortionary cost.[14]

The third intuitive argument in the TI literature cites the "modified Samuelson Rule" that the provision of public goods is justified if the benefits exceed their direct cost by an amount as least as large as the additional welfare cost of raising funds with distortionary taxes (Browning 1976, 283). Since the environment is a public good, Bovenberg and de Mooij (1994) argue that "(i)ntuitively, the collective good of environmental quality directly competes with other collective goods. Hence, the marginal costs of environmental policy rise with the marginal cost of public funds." They add that "high costs of public funds crowd out not only ordinary public consumption, but also the collective good of the environment." Similar intuitive arguments are

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[14] The TI literature frames their analysis in terms of a "gross cost" to environmental tax reform that will exceed "primary cost" (Bovenberg and Goulder 2002). They define gross cost as equaling primary cost plus the tax interaction effect (secondary cost) minus the revenue-recycling effect (secondary benefit). Given these definitions, we would expect at the optimum that (marginal) gross cost will equal marginal environmental gains. But, by itself, these definitions and identities of individual welfare effects do not tell us how the second-best welfare gains compare to the first-best case.

made by Fullerton (1997) and Auerbach and Hines (2002).

Consider the comparability of environmental taxes and traditional public goods provision. In the case of most public goods, revenues must be raised to finance their provision, and as the cost of raising revenues increases due to tax distortions this raises the cost to society of producing the public good, so fewer public goods are justified due to the higher cost. The case of taxation for environmental improvement is somewhat different however. The revenues collected are a byproduct of the incentive mechanism used to discourage pollution and improve environmental quality, not the cost incurred to produce environmental quality via some public works project or centralized abatement (van der Ploeg and Bovenberg 1994). Pollution taxes can improve the collective good of environmental quality before any of the revenues have been spent.

From (12) if the distortionary effects of the environmental tax are higher due to higher distortions, so too are the beneficial revenue recycling effects, if those revenues are used to finance reductions in preexisting taxes. If they are returned lump-sum to the economy, then the tax base effects will represent larger costs the higher are the revenue-raising taxes.

An alternative intuition sees the environment as an endowed public good that is degraded by private actions, and these taxes reduce a “public bad” with the unintended side-effect of making public funds available – for other uses. The relationship between the marginal cost of public funds and justification for environmental policy seems to be in some sense the converse of the modified Samuelson rule. Indeed, consider the following thought experiment. Suppose an economy relies on fossil fuel for energy and that the first-best Pigouvian tax on its pollution generates exactly the level of revenue needed to provide the optimal level of public goods. Call this first-best optimum “scenario B.” Now assume that a technological innovation leads to the complete abandonment of fossil fuels (replaced by a clean solar energy technology). Assume energy costs remain essentially the same due to the higher cost of the technology but zero external costs. The other assumptions of our benchmark model hold. Revenues from environmental taxes falls to zero, however, leaving public goods provision unfinanced. To finance public expenditures, distortionary taxes are introduced but, because of their increased cost, a lower level of public goods is provided. Leaving aside the environmental improvements, welfare is reduced in this new scenario A compared to scenario B due to the provision of fewer public goods and due to the distortionary effects of taxation. Comparing the two scenarios we clearly have a situation where the ability to tax an externality was complementary to the provision of public goods; it did not compete with other public goods, but made it cheaper to provide more of them.[15] Indeed, Metcalf (2003) has shown that in a second-best setting the optimal level of environmental quality will likely be higher than in a first-best setting. The current thought experiment simply draws attention to the symmetrical complementarity from the side of public goods provision.

A more basic intuition for the understanding that emerges here, and for this thought experiment in particular, draws on the principles associated with Henry George about the appropriation of resource rents by government as a costless source of revenue. In scenario B, rents for environmental waste disposal services accrue to the government. In the case of scenario A these rents accrue to the inventors and producers of the solar technology that replaces the environment as a key factor of production, leaving the government to turn to distortionary taxes to raise revenues. A cap-and-trade program for climate change would be similar. Auctioning a fixed number of pollution allowances provides government with a non-distortionary source of revenue – relative to giving the emissions rights away – and reduces the revenue that must be raised using distortionary taxes.

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[15] This thought experiment is comparable to the section III discussion about situations A and B.

VI. Conclusions

Second-best optimal environmental taxation differs from the first-best case because there are two types of marginal benefits and two types of marginal costs to be traded-off. In the first-best setting, primary costs are traded-off against primary (environmental) benefits up to the first-best optimal tax. In a second-best setting there are also fiscal effects to consider. In addition to the Pigouvian tradeoffs, the marginal fiscal benefits (revenue recycling effects) are traded-off against marginal fiscal costs (tax base effects). The central question in the double dividend debate has been about the net welfare changes arising from these differences: whether the welfare gains from revenue-neutral environmental taxation in a second-best setting are larger or smaller than those in a first-best case. The current analysis finds consistent results indicating that for benchmark models broadly consistent with parameters for the U.S. economy, the welfare gains from second-best environmental taxation are larger than those for a comparable first-best setting, and that the second-best optimal environmental tax is higher than the first-best Pigouvian rate. Even in economies where the second-best optimal environmental tax may be lower than its first-best counterpart, this is not sufficient grounds to conclude that the welfare gains are lower than for a first-best setting.

By contrast, the TI literature claims that pre-existing taxes “significantly raise the costs of all environmental policies relative to their costs in a first-best world (Goulder et al. 1999), and that “a potentially major element of social costs has been systematically overlooked in the analysis of a wide class of public programs and economic institutions” (Parry and Oates 2000). In one example the net effect is estimated to raise the costs of an emissions tax by 27% above the first-best case (Goulder et al., 1999).

These interpretations in the TI literature are found here to be due to the highly indirect approach taken for evaluating the welfare gains from environmental taxation. Rather than evaluate the welfare changes directly, this literature set out to test whether the second-best optimal environmental tax was higher or lower than the first-best Pigouvian tax: By implication, if the optimal environmental tax was higher (lower) than the first-best Pigouvian rate, this would indicate that the welfare effects were larger (smaller) than in a first-best setting.

This indirect test, however, is not actually performed anywhere in the TI literature. In most cases, rather than comparing the second-best optimal environmental tax to the first-best Pigouvian rate, the second-best optimal environmental tax is compared instead to an expression for MSD^2. And although the Pigouvian rate is equal to MSD^1 in a first-best setting, the definition of MSD^2 in a second-best setting is ambiguous and, depending on which definition is used, its value varies with the level of taxes and with the tax normalization. It follows that comparing the second-best optimal environmental tax to one of six possible measures of MSD^2 is an unreliable proxy for the first-best Pigouvian rate. It will be higher for some definitions and lower for others. The use of an income tax normalization adds an additional source of confusion by creating a divergence between the effective and nominal environmental tax, and this also makes the units of private income a function of the labor tax rate. As a result, the use of both an income tax normalization and the private marginal utility of income as the numeraire compounds the ambiguity and confusion.

Early contributions promoting the double dividend hypothesis, from Tullock (1967) to Terkla (1984), focused on these fiscal benefits but ignored the costs associated with the tax base effects. The important contribution of the tax interaction literature has been to recognize that there were both fiscal benefits and fiscal costs associated with environmental taxation – as with any tax pertinent to raising revenues. These insights suggest that, in principle, the second-best optimal environmental tax could be lower than the first-best Pigouvian rate if the tax base effects are larger than the revenue recycling benefits. In practice, however, the opposite is found to be true with the benchmark models used in the TI literature. The “effective” second-best optimal environmental tax is found to be about one-third higher than the first-best Pigouvian rate. Indeed, this same result is implicit in Bovenberg and Goulder’s (1997) carbon tax numerical model when expressed in terms of a commodity tax normalization.

The implementation of environmental taxes is a different issue altogether. In an economy that relies on income taxes for revenue, a given nominal environmental tax will represent a higher “effective” environmental tax than reflected in the nominal tax rate. As a result of this, the nominal tax on pollution in a second-best setting may indeed decline with rising revenue requirements and income taxes compared to the first-best Pigouvian rate. The effective tax on pollution, the welfare gains from environmental tax reform, and the optimal level of environmental quality, however, are all consistent with the finding that the secondary fiscal benefits (revenue recycling effects) exceed the secondary fiscal costs (tax base effects) over a range of environmental tax rates up to and exceeding the first-best Pigouvian rate. And these findings are consistent with the “strong form” of the double dividend hypothesis as defined by Fullerton (1997) in reference to the benchmark models under consideration.

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