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Environmental taxes and labor-market distortions

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Abstract

It is sometimes argued that by using the revenues from environmental taxes to reduce distortionary taxes on labor, governments can reap a 'double dividend', namely, not only an improvement in environmental quality, but also a reduction in the efficiency costs associated with raising public revenue. By employing a general equilibrium model, this paper finds that, contrary to common wisdom, environmental taxes typically render the overall tax system a less efficient instrument to finance public spending. Furthermore, high estimates for the marginal efficiency costs of existing taxes weaken, rather than strengthen, the case for environmental taxes.

Keywords: Environmental tax; Excess burden; Second best; Double dividend

JEL classification: H23; Q28

1. Introduction

In the face of growing concern about serious environmental problems, environmental taxation has attracted increasing attention as taxes can, at least in principle,

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internalize the external effects of environmental damage. Furthermore, many economists have argued that environmental taxes are an efficient instrument for achieving environmental objectives (see, e.g, Baumol and Oates (1988) and Pearce and Turner (1990)).

Some have gone even further to suggest that environmental taxes may yield benefits over and above a cleaner environment if the Laffer curve for these taxes is upward sloping; by using the revenues from environmental taxes to decrease other, distortionary taxes, the government can reduce the overall economic costs of financing public spending (see e.g. Repetto et al. (1992) and Nordhaus (1993)). In this way, it is argued, environmental taxes yield a 'double dividend' – not only a cleaner environment but also a less distortionary tax system. Indeed, high estimates for the marginal efficiency costs of the existing tax system have been put forward as an important argument in support of environmental taxes. To illustrate, in advocating carbon taxes, Pearce (1991) presents estimates for the deadweight losses of current tax systems (see also Oates (1991)).

The objective of this paper is to explore under which conditions environmental taxes do indeed reduce the efficiency costs of financing public spending. To that end, it formulates a simple general equilibrium model of a small open economy. The model is designed to examine the interaction between, on the one hand, environmental taxes aimed at internalizing the external effects from pollution, and, on the other hand, distortionary taxes on labor designed to finance public spending. The model thus contains two distortions: first, an environmental distortion associated with the external effects of pollution and, second, a distortion in the labor market on account of a distortionary tax on labor income.

The double dividend argument has also been explored by Bovenberg and Van der Ploeg (1994). This particular study assumes that taxes and spending are set optimally. Our paper, in contrast, belongs to the literature on tax reform (see, e.g. Ahmad and Stern (1984)) rather than that on optimal taxation. In particular, we explore the macro-economic impact and the welfare effects of an environmental tax reform, i.e. increasing pollution levies and using the revenues to cut distortionary taxes on labor. We believe that our paper is a useful complement to optimal tax exercises because the implementation of optimal tax structures typically requires information that is not readily available. Hence, tax-reform analysis is important for policy making in practice. Our paper differs from Bovenberg and Van der Ploeg (1994) also because we take government spending to be exogenously given. Most policy discussions on the double dividend do indeed assume that government spending is kept constant.

The remainder of the paper is organized as follows. Section 2 elaborates on the model. The next two sections present and interpret the effects of an increase in environmental taxes for the case where the revenues are used to reduce the tax rate on labor income. In order to understand the basic intuition behind the results, Section 3 examines the economic effects if environmental taxes are introduced in an initial equilibrium without any environmental taxes. The case with positive initial environmental taxes is dealt with in Section 4. Section 5 presents some suggestions for extending the model. Finally, Section 6 contains the main conclusions.

2. The model

The model assumes a small open economy, which faces exogenous world-market prices for commodities and capital. Labor is immobile internationally. Hence, the wage rate is the only price that is determined endogenously. This section describes the main features of the model, which is contained in Table 1. The notation is explained at the end of the paper.

Firm behavior: Production

A representative firm supplies a single commodity (Y). A constant-returns-to-scale neo-classical production function (I.1) describes domestic production. Besides labor (L_d) and capital (K), a third input (E) enters the production function. This input causes environmental damage when used in production. Accordingly, it is called the 'polluting' input and can be thought off as energy.

The first-order conditions (I.2), (I.3), and (I.4) represent the implicit demands for, respectively, labor, capital, and the polluting input. The production function assumes that capital and the polluting input form a composite input before combining with labor (see Fig. 1). The particular production structure is chosen because empirical evidence suggests that energy and capital are complements. Capital is included to give the model a more realistic flavor. Moreover, it allows us to model labor as a better substitute for resources than capital. The non-profit condition (I.5) follows from the assumptions of constant returns to scale, perfect competition, and profit maximization. Price equations (I.6) and (I.7) link the prices faced by the firm (the so-called 'producer' prices) to the market prices of labor and the polluting input.

Household behavior: Consumption and labor supply

Household behavior is derived from optimizing utility (I.8). Households demand two consumption commodities. One of these commodities – the so-called 'polluting' consumption commodity (D) – harms the environment when consumed. The other commodity is called the 'non-polluting' consumption commodity (C). [1] The substitution elasticity between the two consumption commodities is denoted by σ_q.

In addition to these two consumption commodities, leisure (V) and environmental quality (M) (i.e. environmental services) enter utility (Fig. 2). Leisure is

[1] This commodity, however, may cause environmental damage when it is produced.

Table 1
The model in levels

Firms		
Production function	$Y = F[L_d, N(K,E)]$	(I.1)
First-order conditions	$P_y \frac{\partial Y}{\partial L_d} = P_l^f$	(I.2)
	$P_y \frac{\partial Y}{\partial K} = P_y \frac{\partial F}{\partial N} \frac{\partial N}{\partial K} = r$	(I.3)
	$P_y \frac{\partial Y}{\partial E} = P_y \frac{\partial F}{\partial N} \frac{\partial N}{\partial E} = P_e^f$	(I.4)
Non-profit condition	$P_y Y = P_l^f L_d + P_e^f E + rK$	(I.5)
Price equations	$P_l^f = (1 + t_l) P_l$	(I.6)
	$P_e^f = P_e + t_e$	(I.7)
Households		
Utility function	$U = U[M, H\{V, Q(C, D)\}]$	(I.8)
Household budget constraint	$P_c C + P_d^h D = P_l L$	(I.9)
First-order conditions	$\frac{\partial U}{\partial H} \frac{\partial H}{\partial V} = \lambda P_l$	(I.10)
	$\frac{\partial U}{\partial C} = \frac{\partial U}{\partial H} \frac{\partial H}{\partial Q} \frac{\partial Q}{\partial C} = \lambda P_c$	(I.11)
	$\frac{\partial U}{\partial D} = \frac{\partial U}{\partial H} \frac{\partial H}{\partial Q} \frac{\partial Q}{\partial D} = \lambda P_d^h$	(I.12)
Price equation	$P_d^h = P_d + t_d$	(I.13)
Government		
Balanced budget	$P_g G = t_e E + t_d D + t_l P_l L$	(I.14)
Equilibrium on the labor market	$L_d = L_s$	(I.15)
Balance of payments	$P_e E + rK + P_d D + P_c C + P_g G = P_y Y$	(I.16)
Environmental quality	$M = M(E,D)$	(I.17)

assumed to be weakly separable from the two produced commodities C and D. This enables us to solve the model analytically. Moreover, there is no strong empirical evidence suggesting that separability does not hold if we associate dirty consumption with energy use by households. The environment is a collective good and weakly separable from private goods. Accordingly, households take the quality of the environment as given. Just as the firms, they ignore the adverse effect of their demand for polluting goods on the quality of the environment. We thus abstract from altruism and Coasian bargaining. Households adopt the demands for leisure and the two consumption commodities as instruments to

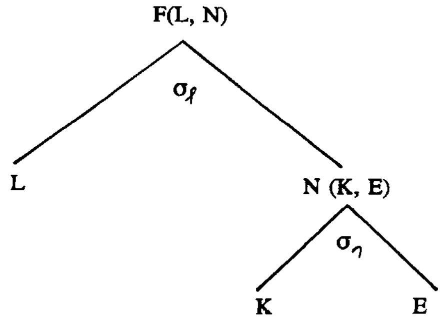

Fig. 1. The production structure.

optimize utility subject to a budget constraint (I.9). In particular, private consumption is constrained by labor income ($P_l L$). The implicit expressions for labor supply (L_s) and the demand for the two consumption commodities are given by the first-order conditions (I.10), (I.11), and (I.12). Eq. (I.13) shows that the environmental tax on the polluting commodity raises the household price of this commodity (P_d^h) above its market price (P_d).

Government

The government budget is balanced (see (I.14)). Government spending on public goods (G) is financed by three taxes: an ad-valorem tax on labor income (t_l) and two specific environmental taxes. One of these latter taxes applies to the polluting consumption commodity demanded by households (t_d). The other environmental tax is levied on the demand by firms for the polluting input into the production process (t_e).

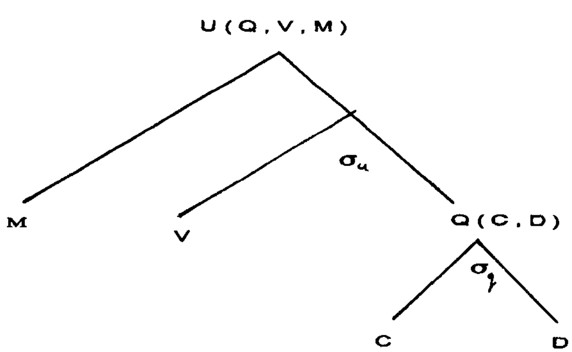

Fig. 2. The structure of the utility function.

International trade and labor-market equilibrium

All commodities (i.e. the polluting input, the two consumption commodities, the domestic output, and the public good) are tradable. Accordingly, their prices (before taxes) are determined on world markets and are exogenous to the economy. An example of a tradable polluting input and a tradable polluting consumption good is fossil fuel. Also the rate of return on capital is exogenous to the small open economy because capital is perfectly mobile internationally. [2] Labor, in contrast, is assumed to be immobile. Accordingly, the wage rate is the only price that is determined domestically. Expression (I.15) denotes labor market equilibrium. The balance-of-payments constraint (I.16) represents the budget constraint for the economy as a whole. The value of the domestic production of tradables constrains overall domestic demand for tradables. [3] As far as the relationship between the produced output and the commodities that are demanded by domestic agents is concerned, two alternative interpretations of the fixed producer prices P_y, P_e, P_d, P_c, and P_g are possible. One interpretation is that the latter commodities are produced domestically. Producer prices are fixed because the rates of transformation are assumed to be constant. An alternative interpretation is that the commodities that are demanded domestically are imported at fixed world-market prices. These goods are paid for by exports of domestically produced commodities. [4]

Environmental relationships

Expression (I.17) formalizes the inverse relationship between the quality of the natural environment and the demand for, respectively, polluting consumption commodities and polluting inputs into production. This relationship raises spacial and dynamic issues. The static model abstracts from lags between economic activity and environmental damage associated with stock-flow effects. If pollution crosses international borders, the link between, on the one hand, domestic consumption and production, and, on the other hand, the quality of the domestic natural environment, is weakened.

Linearized model

This paper examines the local behavior of the small open economy around the initial equilibrium. To that end, the model is log-linearized around the initial

[2] Capital can also be interpreted as a tradable non-polluting input.

[3] In accordance with the Law of Walras, this constraint can be derived from equilibrium on the labor market (I.15), the non-profit condition (I.5), and the budget constraints of, respectively, households and the government (i.e. (I.9) and (I.14)).

[4] These two interpretations can also be combined: Some commodities (for example, the clean consumption commodity and the public consumption good) can be produced domestically while other goods (for example, the dirty goods, i.e. fossil fuels) are imported at exogenous world-market prices.

equilibrium. [5] Table 2 contains the log-linearized model. The notation is explained at the end of the table. A tilde (~) denotes a relative change, unless indicated otherwise. The prices of the tradable commodities and mobile capital are given from abroad. This paper assumes that these exogenous variables do not change. Appendix A solves the log-linearized model for changes in the two environmental taxes. In order to examine a change in the tax mix, we assume that the government keeps its own spending on public goods constant and adopts the (endogenous) tax rate on labor to balance its budget.

The excess burden

One can measure the welfare effects of small policy changes by the so-called marginal 'excess burden'. [6] This marginal excess burden corresponds to the additional income that needs to be provided to the representative household to keep its utility at its initial level (i.e. without the policy shock). Hence, a positive value for the marginal excess burden indicates a loss in welfare. In order to provide more intuition for the welfare effects, three alternative expressions for the marginal excess burden are presented.

The marginal excess burden (as a ratio to initial household income, $P_l L$), $\tilde{\beta}$, can be written as the sum of effects on the environmental and labor-market distortions (the various shares and elasticities are defined at the end of table 2): [7]

$$\tilde{\beta} = -\frac{\beta_l}{\alpha_q}\tilde{L} - \left(\frac{\beta_d}{\alpha_q} - \eta\theta_d\right)\tilde{D} - \left(\frac{\beta_e}{\alpha_q} - \eta\theta_e\right)\tilde{E}. \tag{2.1}$$

The first term at the right-hand side of (2.1) stands for the effect on the labor-market distortion, which is due to a distortionary tax on labor income. In particular, the tax rate on labor income measures the marginal welfare gain associated with an additional unit of employment. Thus, if the tax rate on wage income is positive, an expansion of employment raises welfare. Intuitively, at the margin, the social benefits of employment exceed the social opportunity costs because the additional production from one additional unit of labor not only compensates the worker for giving up leisure but also yields tax revenue. Hence, by strengthening the economic base of the public sector, employment yields a public benefit to society over and above the compensation to the private supplier of labor.

[5] This procedure is based on Keller (1980).

[6] This burden is called the 'excess' burden because it corresponds to the loss in welfare over and above the revenues collected by the government. One can interpret the costs due to the excess burden as the 'hidden' costs of financing public spending because they are not reflected in tax revenue.

[7] See Appendix B for the derivation. This expression for the 'marginal' excess burden holds exactly only for infinitely small changes in taxes. It is an approximation for the welfare effects of larger changes. For a discussion of welfare measures, in general, and the marginal excess burden, in particular, see Fullerton (1991).

The last two terms at the right-hand side of (2.1) correspond to the effects on the environmental distortions, which are due to, respectively, pollution in consumption and in production. The welfare effect of a marginal increase in the demand for the polluting commodities is given by the difference between, on the one hand, a tax term, which measures the social benefits of additional tax revenue due to a wider tax base, and, on the other hand, the marginal social damage from pollution. In the absence of environmental taxes (i.e. $\beta_d = \beta_e = 0$), cutting the demand for the polluting commodities enhances overall welfare because the social costs of pollution exceed the social benefits. In the presence of initial environmental taxes, a lower demand for polluting commodities harms welfare if the 'tax-base' effect exceeds the pollution effect. If the tax rate is set to fully internalize the external effects of pollution, the effect on the tax base exactly offsets the social damage of pollution (i.e. $(\beta_i/\alpha_q) = \eta\theta_i$ for $i = d, e$). In that case, the last terms at the right-hand side are zero and a marginal change in the demand for polluting commodities does not affect welfare. Intuitively, a higher demand for polluting commodities causes additional social costs in terms of environmental damage, which are exactly offset by the social contribution in terms of additional tax revenue.

The marginal welfare effects differ from the overall welfare costs of the tax system as computed by Harberger (1974). Whereas Harberger measures the welfare costs of the tax system as a whole, we only consider marginal changes in welfare due to small tax reforms. Harberger in effect compares the tax system with the case of no taxes and hence analyzes large changes in taxes. Therefore, he considers not only first-order welfare effects but also the second-order effects. We believe that the case with no taxes at all is rather hypothetical and thus prefer the analysis of small changes in taxes. This has the additional advantage that only local information about the various elasticities is required.

By rearranging the terms in expression (2.1), one can alternatively display the marginal excess burden as the sum of an effect on the tax base, $\tilde{b}^t$, and an effect on the quality of the environment, $\tilde{b}^e$:

$$\tilde{\beta} = -\tilde{b}^t - \tilde{b}^e. \tag{2.2}$$

The effect on 'environmental' income, $\tilde{b}^e$, can be separated into the effects on environmental quality due to changes in household- and firm behavior, respectively:

$$\tilde{b}^e = -\eta\left[\theta_d\tilde{D} + \theta_e\tilde{E}\right]. \tag{2.3}$$

The 'tax-base' effect, $\tilde{b}^t$, is defined by

$$\alpha_q\tilde{b}^t = \beta_l\tilde{L} + \beta_d\tilde{D} + \beta_e\tilde{E}. \tag{2.4}$$

The three terms at the right-hand side of (2.4) stand for the effects on the base of, respectively, the labor tax, the environmental tax on household consumption, and

Table 2
The model in relative changes

Firms		
Supply of domestic commodity	$\tilde{Y} = \alpha_{lf}\tilde{L}_d + \alpha_{ef}\tilde{E} + \alpha_k\tilde{K}$	(II.1)
Labor demand	$\tilde{L}_d = \tilde{Y} + \sigma_l[\alpha_{ef}(\tilde{P}_e^f - \tilde{P}_l^f) + \alpha_k(\tilde{r} - \tilde{P}_l^f)]$	(II.2)
Demand for capital services	$\tilde{K} = \tilde{Y} + \sigma_l\alpha_{lf}[\tilde{P}_l^f - \tilde{r}] + \dfrac{\alpha_{ef}}{\alpha_{ef} + \alpha_k}[\sigma_n - \sigma_l\alpha_{lf}](\tilde{P}_e^f - \tilde{r})$	(II.3)
Demand for polluting inputs	$\tilde{E} = \tilde{Y} + \sigma_l\alpha_{lf}[\tilde{P}_l^f - \tilde{P}_e^f] + \dfrac{\alpha_k}{\alpha_{ef} + \alpha_k}[\sigma_n - \sigma_l\alpha_{lf}](\tilde{r} - \tilde{P}_e^f)$	(II.4)
Non-profit condition	$\tilde{P}_y = \alpha_{lf}\tilde{P}_l^f + \alpha_{ef}\tilde{P}_e^f + \alpha_k\tilde{r}$	(II.5)
Before-tax wage rate	$\tilde{P}_l^f = \tilde{P}_l + \tilde{t}_l$	(II.6)
Price of polluting inputs faced by firms	$\tilde{P}_e^f = (1 - \dfrac{t_e}{P_e^f})\tilde{P}_e + \tilde{t}_e$	(II.7)
Households		
Budget constraint for households	$\tilde{P}_q + \tilde{Q} = \tilde{P}_l + \tilde{L}_s$	(II.8)
Labor supply	$\tilde{L}_s = \theta_{ll}\tilde{P}_l^n$	(II.9)
Demand for the 'clean' commodity by households	$\tilde{C} = \tilde{Q} + (1 - \phi_c)\sigma_q(\tilde{P}_d^h - \tilde{P}_c)$	(II.10)
Demand for the polluting commodity by households	$\tilde{D} = \tilde{Q} - \phi_c\sigma_q(\tilde{P}_d^h - \tilde{P}_c)$	(II.11)
Price level of the consumption bundle	$\tilde{P}_q = \phi_c\tilde{P}_c + (1 - \phi_c)\tilde{P}_d^h$	(II.12)
Real after-tax wage rate	$\tilde{P}_l^n = \tilde{P}_l - \tilde{P}_q$	(II.13)
Household price for polluting consumption commodities	$\tilde{P}_d^h = \left(1 - \dfrac{t_d}{P_d^h}\right)\tilde{P}_d + \tilde{t}_d$	(II.14)
Government		
Balanced budget	$\alpha_g(\tilde{P}_g + \tilde{G}) = \alpha_{ef}\tilde{t}_e + \alpha_{dh}\tilde{t}_d + \alpha_{lf}\tilde{t}_l + \beta_e\tilde{E} + \beta_d\tilde{D} + \beta_l(\tilde{P}_l + \tilde{L})$	(II.15)
Equilibrium		
Labor-market	$\tilde{L}_s = \tilde{L}_d$	(II.16)
Walras law		
Balance of payments	$\tilde{Y} + \tilde{P}_y = \alpha_k(\tilde{K} + \tilde{r}) + \alpha_e(\tilde{E} + \tilde{P}_e) + \alpha_d(\tilde{D} + \tilde{P}_d) + \alpha_c(\tilde{C} + \tilde{P}_c) + \alpha_g(\tilde{G} + \tilde{P}_g)$	(II.17)

Table 2 (continued)

Environmental quality

$$\tilde{M} = -\theta_e \tilde{E} - \theta_d \tilde{D} \qquad \text{(II.18)}$$

Endogenous variables:

$\tilde{Y}, \tilde{L}_d, \tilde{K}, \tilde{E}, \tilde{P}_l^f, \tilde{P}_e^f, \tilde{Q}, \tilde{L}_s, \tilde{D}, \tilde{C}, \tilde{P}_q, \tilde{P}_l^n, \tilde{P}_d^h, \tilde{P}_l, \tilde{M}, \tilde{t}_l$

Exogenous variables:

$\tilde{P}_e = \tilde{P}_d = \tilde{r} = \tilde{P}_y = \tilde{P}_c = \tilde{P}_g = \tilde{G} = 0, \tilde{t}_e, \tilde{t}_d \geq 0$

Notation Table II:

Taxes: $\tilde{t}_l = \dfrac{\Delta t_l}{1+t_l}, \tilde{t}_e = \dfrac{\Delta t_e}{P_e^f}, \tilde{t}_d = \dfrac{\Delta t_d}{P_d^h}$

Basic parameters

σ_l = substitution elasticity between labor and the composite production factor in production
σ_n = substitution elasticity between capital and polluting inputs in production
σ_q = substitution elasticity between dirty and clean consumption commodities
σ_u = substitution elasticity between leisure and consumption
θ_e = elasticity that measures the relative change in M due to a rise in E
θ_d = elasticity that measures the relative change in M due to a rise in D
$\eta = \dfrac{\partial U/\partial M}{\partial U/\partial Q}\dfrac{M}{Q}$ the marginal rate of substitution between M and Q, multiplied by M/Q
$\delta = L_s/V$ labor-leisure ratio

Derived parameters

$\theta_l = 1/(1+\delta)$ income elasticity of labor supply
$\theta_{ll} = \sigma_u \theta_l$ uncompensated wage elasticity of labor supply
$\theta_{ll}^* = \theta_{ll} + \theta_l$ compensated wage elasticity of labor supply
$\sigma_l^* = \dfrac{\alpha_k}{\alpha_k + \alpha_{ef}}\sigma_n + \dfrac{\alpha_{ef}}{\alpha_k + \alpha_{ef}}\dfrac{\sigma_l}{\alpha_{lf}}$
$Z = \alpha_d + \alpha_c$
$R = \beta_l + \beta_e + \beta_d$
$\det = Z + \theta_l R - \theta_{ll}^* R$

Shares

α_{lf}	$= P_l^f L/P_y Y$	α_{dh}	$= P_d^h D/P_y Y$
α_{ef}	$= P_e^f E/P_y Y$	α_d	$= P_d D/P_y Y$
α_e	$= P_e E/P_y Y$	α_q	$= P_q Q/P_y Y = P_l L/P_y Y$
α_k	$= rK/P_y Y$	α_c	$= P_c C/P_y Y$
		ϕ_c	$= \alpha_c/\alpha_q$
α_g	$= P_g G/P_y Y$		
β_d	$= t_d D/P_y Y$		
β_e	$= t_e E/P_y Y$		
β_l	$= t_l p_l L/P_y Y$		

the environmental tax levied on firm input. Intuitively, the tax-base effect represents the consequences of a different tax mix for the efficiency of the tax system as an instrument to raise revenue. In particular, an erosion of the tax base indicates that the tax system becomes less efficient as a revenue-raising device as higher tax rates are required to collect the same amount of revenue. Consequently, although it collects the same overall revenues, the government has to impose higher marginal

Table 3
Reduced-form coefficients [a]

	$\tilde{t}_d$	$\tilde{t}_e$
$\tilde{Y}$	$-\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det}<0$	$-\frac{\theta_{ll}\beta_e\sigma_l^*}{\det}<0$ $-\frac{\alpha_{ef}}{\alpha_{lf}}\sigma_l<0$
$\tilde{L}$	$-\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det}<0$	$-\frac{\theta_{ll}\beta_e\sigma_l^*}{\det}<0$
$\tilde{E}$	$-\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det}<0$	$-\frac{\theta_{ll}\beta_e\sigma_l^*}{\det}<0$ $-\sigma_l^*<0$
$\tilde{K}$	$-\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det}<0$	$-\frac{\theta_{ll}\beta_e\sigma_l^*}{\det}<0$ $\sigma_n-\sigma_l^*>?<0$
$\tilde{D}$	$-\frac{(1+\theta_{ll})\beta_d\phi_c\sigma_q}{\det}<0$ $-\phi_c\sigma_q<0$	$-\frac{(1+\theta_{ll})\beta_e\sigma_l^*}{\det}<0$
$\tilde{C}$	$-\frac{(1+\theta_{ll})\beta_d\phi_c\sigma_q}{\det}<0$ $+(1-\phi_c)\sigma_q>0$	$-\frac{(1+\theta_{ll})\beta_e\sigma_l^*}{\det}<0$
$\tilde{P}_l^n$	$-\frac{\beta_d\phi_c\sigma_q}{\det}<0$	$-\frac{\beta_e\sigma_l^*}{\det}<0$
$\tilde{p}_l$	$-\frac{\beta_d\phi_c\sigma_q}{\det}<0$ $+(1-\phi_c)>0$	$-\frac{\beta_e\sigma_l^*}{\det}<0$
$\tilde{P}_l^f$	0	$-\frac{\alpha_{ef}}{\alpha_{lf}}<0$
$\tilde{t}_l$	$+\frac{\beta_d\phi_c\sigma_q}{\det}>0$ $-(1-\phi_c)<0$	$-\frac{\alpha_{ef}}{\alpha_{lf}}<0$ $+\frac{\beta_e\sigma_l^*}{\det}>0$
$\tilde{b}^e$	$+\eta[\theta_e\theta_{ll}+\theta_d(1+\theta_{ll})]\frac{\beta_d\phi_c\sigma_q}{\det}>0$ $+\eta\theta_d\phi_c\sigma_d>0$	$+\eta[\theta_e\theta_{ll}+\theta_d(1+\theta_{ll})]\frac{\beta_e\sigma_l^*}{\det}>0$ $+\eta\theta_e\sigma_l^*>0$

[a] $\det = Z+\theta_l R-\theta_{ll}^* R$.

taxes. Accordingly, the loss in private income in excess of the collected revenue, i.e. the marginal excess burden, rises.

The tax-base effect (2.4) is equal to the relative change in real after-tax wages (see Appendix B).

$$\tilde{b}^t = \tilde{P}_l^n. \tag{2.5}$$

Accordingly, households suffer a loss in income if the tax system becomes a less efficient instrument to finance public spending. The overall excess burden (2.2) amounts to the sum of effects on real wage income, $\tilde{P}_l^n$, and environmental income (2.3). Thus, even though households may suffer a decline in real wage income due to a less efficient tax system, they may nevertheless gain in terms of overall utility if a rise in environmental income more than offsets the adverse effect on wage income.

3. The case without initial environmental taxes

This section discusses how the endogenous variables are affected in the case where environmental taxes are introduced in an equilibrium without any environmental taxes (i.e. $\beta_d = \beta_e = 0$).

Tax on the polluting consumption commodity

The first column of Table 3 (the first and second rows with $\beta_d = 0$) reveals that in this case the introduction of a small environmental tax on households (with the revenue used to lower the tax rate on labor) affects neither employment nor production. Intuitively, this tax does not directly impact production. Hence, the marginal productivity of labor and, therefore, the before-tax wage, P_l^f, and the demand for labor remain unaffected:

$$\tilde{P}_l^f = 0. \tag{3.1}$$

The lower tax on labor income allows for a rise in the market price of labor (i.e. the wage after labor taxes but before (indirect) consumption taxes), P_l:

$$\tilde{P}_l = -\tilde{t}_l. \tag{3.2}$$

However, the wage rate that affects the incentives to supply labor (see expression (II.9) in Table 2) is not the market wage but the real after-tax wage (i.e. the wage after not only labor taxes but also (indirect) consumption taxes), P_l^n. The environmental tax on households drives a wedge between the market wage and the real after-tax wage:

$$\tilde{P}_l^n = \tilde{P}_l - (1 - \phi_c)\tilde{t}_d. \tag{3.3}$$

Accordingly, the wedge between the before-tax and real after-tax wages consists of not only the distortionary tax on labor but also the environmental tax on consumption:

$$\tilde{P}_l^f - \tilde{P}_l^n = \tilde{t}_l + \left(\tilde{P}_l - \tilde{P}_l^n\right) = \tilde{t}_l + (1 - \phi_c)\tilde{t}_d. \tag{3.4}$$

Whether replacing the labor tax by the environmental tax stimulates labor supply by raising the real after-tax wage depends on whether lower taxes on labor more than offset the effect of the higher environmental tax on the overall wedge (3.4). In order to find the cut in labor taxes made possible by the higher environmental tax, one needs the budget constraint of the government: [8]

$$\tilde{t}_l + (1 - \phi_c)\tilde{t}_d = -\tilde{b}^t. \tag{3.5}$$

The right-hand side of (3.5) equals the tax base effect. This term is zero if employment is unaffected and if there are no initial environmental taxes. Accordingly, the higher environmental tax exactly offsets the effect of the lower labor tax on the wedge between the before- and after-tax real wage. Indeed, given the constraint of revenue neutrality and the same bases for the taxes on consumption and labor income, replacing the tax on labor income by an indirect (environmental) tax on consumption affects only the composition of the wedge between before- and after-tax wages without affecting the overall magnitude of this tax distortion (see also Poterba (1991, p. 19)).

Tax on the polluting input into production

The second column of Table 3 provides the results for an environmental tax on production. Also this tax leaves employment unaffected (as $\beta_e = 0$). The reasons are as follows. The production tax reduces the demand for polluting inputs, which contributes to a cut in domestic production. Hence, labor productivity falls if employment remains constant. This, in turn, causes a decline in the before-tax wage. In particular, the non-profit condition (II.5) yields the following relationship between the tax on the polluting input and the before-tax wage:

$$\tilde{P}_l^f = -\frac{\alpha_{ef}}{\alpha_{lf}}\tilde{t}_e. \tag{3.6}$$

Accordingly, the input tax is borne by the immobile factor labor; since both polluting inputs and capital are perfectly mobile internationally, they can shift the entire burden of the tax to labor.

In order to determine the impact on labor supply, we need to examine the effect on the real after-tax wage. This effect corresponds to that on the market wage because the environmental tax on households, and therefore the consumption price

[8] This equation follows from substituting (3.2) into (II.15) in Table 2 and using the definition of the tax-base effect (2.4).

Table 4
The marginal excess burden $\tilde{\beta}$ [a]

	$\tilde{t}_d$	$\tilde{t}_e$
$-\frac{\beta_l}{\alpha_q}\tilde{L}$	$+\frac{\beta_l}{\alpha_q}\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det} > 0$	$+\frac{\beta_l}{\alpha_q}\frac{\theta_{ll}\beta_e\sigma_l^*}{\det} > 0$
$\left(\eta\theta_d - \frac{\beta_d}{\alpha_q}\right)\tilde{D}$	$-\left(\eta\theta_d - \frac{\beta_d}{\alpha_q}\right)\phi_c\sigma_q < 0$ $-\left(\eta\theta_d - \frac{\beta_d}{\alpha_q}\right)\frac{(1+\theta_{ll})\beta_d\phi_c\sigma_q}{\det} < 0$	$-\left(\eta\theta_d - \frac{\beta_d}{\alpha_q}\right)\frac{(1+\theta_{ll})\beta_e\sigma_l^*}{\det} < 0$
$\left(\eta\theta_e - \frac{\beta_e}{\alpha_q}\right)\tilde{E}$	$-\left(\eta\theta_e - \frac{\beta_e}{\alpha_q}\right)\frac{\theta_{ll}\beta_d\phi_c\sigma_q}{\det} < 0$	$-\left(\eta\theta_e - \frac{\beta_e}{\alpha_q}\right)\sigma_l^* < 0$ $-\left(\eta\theta_e - \frac{\beta_e}{\alpha_q}\right)\frac{\theta_{ll}\beta_e\sigma_l^*}{\det} < 0$

[a] $\tilde{\beta} = -\frac{\beta_l}{\alpha_q}\tilde{L} + \left(\eta\theta_e - \frac{\beta_e}{\alpha_q}\right)\tilde{E} + \left(\eta\theta_d - \frac{\beta_d}{\alpha_q}\right)\tilde{D}$

index, is unchanged. How the market wage is affected depends on the balance between, on the one hand, a lower before-tax wage and, on the other hand, the cut in the labor tax allowed by the additional revenues from the environmental tax on production:

$$\tilde{P}_l = \tilde{P}_l^f - \tilde{t}_l = -\left[\tilde{t}_l + \frac{\alpha_{ef}}{\alpha_{lf}}\tilde{t}_e\right]. \tag{3.7}$$

The public-budget constraint (II.15) yields the following relationship between the cut in the tax rate on labor and the rise in the environmental tax on production:

$$\tilde{t}_l + \frac{\alpha_{ef}}{\alpha_{lf}}\tilde{t}_e = -\tilde{b}^t. \tag{3.8}$$

The tax-base effect on the right-hand side of (3.8) is zero if employment does not change because the initial environmental taxes are zero (see (2.4)). Hence, by combining (3.7) and (3.8), one finds that the after-tax wage is not affected; given the constraint of revenue neutrality, the adverse effect of the lower before-tax wage on the after-tax wage is exactly offset by the positive effect of lower taxes on labor income. In a small open economy, substituting a labor tax by a tax on polluting inputs amounts to substituting an implicit tax for an explicit tax on labor. Hence, the overall tax burden on labor is unaffected.

Welfare effects

Starting from an equilibrium without any environmental taxes, the overall welfare effects of small increases in these taxes are positive (see Table 4).

Whereas environmental taxes do not affect employment and, therefore, the distortion in the labor market, they do alleviate the environmental distortion by cutting pollution. In other words, small environmental taxes benefit the environment without affecting the capacity of the tax system to raise revenue, as the tax-base effect is zero.

4. The case with positive initial environmental taxes

The previous section showed that, starting from a situation without any environmental taxes, a small increase in these taxes would not affect employment and would enhance welfare. This result, however, holds only for very small environmental taxes. In order to gain some insight into the effects of large environmental taxes, this section explores the effects of a marginal increase in environmental taxes, starting from an equilibrium in which environmental taxes are positive.

4.1. Tax on the polluting consumption commodity

Effects on employment

For the case where the initial environmental taxes are positive (i.e. $\beta_d > 0$), the first and second rows of the first column in Table 3 show that an increase in the consumption tax on polluting commodities reduces both employment and production if the uncompensated wage elasticity of labor supply is positive (i.e. $\theta_{ll} > 0$). The rest of this paper assumes that the labor-supply curve is indeed upward-bending because most empirical studies yield positive estimates for this elasticity. [9]

It may seem surprising that uncompensated rather than compensated elasticities determine the response of employment. With exogenous government spending on public goods, a first-order income effect would not be expected. However, the environmental tax reform raises the supply of the public good of the environment. In this way, it raises the overall tax burden and imposes a first-order income loss on private agents. Indeed, the appearance of the uncompensated elasticities is consistent with the literature on the marginal cost of public funds. This literature shows that uncompensated rather than compensated elasticities are relevant in computing the marginal cost of public funds as long as the funds are used to finance public goods that are weakly separable from private goods (see Ballard and Fullerton (1992)). If public spending were a perfect substitute for private income, in contrast, compensated elasticities would be relevant. In that case, there would be no first-order income effect as the benefit of additional public spending

[9] Estimates for the wage elasticity of labor supply for men tend to be very small. However, the corresponding elasticity for women is generally estimated to be positive. See, e.g., Hausman (1985).

would offset the costs of the higher tax burden. We have assumed, however, that the natural environment is weakly separable from private commodities. Hence, uncompensated elasticities are relevant.

The negative effect on production and employment is due to a reduction in the real after-tax wage and, therefore, the incentives to supply labor. The negative effect on the real after-tax wage comes about because the lower tax rate on labor income does not fully compensate workers for the adverse effect of the higher environmental tax on their real after-tax wage. This incomplete offset is due to the erosion of the base of the environmental tax. In particular, the higher environmental tax induces households to switch from polluting to non-polluting consumption commodities. If the initial tax rate on the polluting commodities is positive, this behavioral effect erodes the base of the environmental tax and, therefore, produces a negative tax-base effect (i.e. $\tilde{b}^t < 0$). [10] Expressions (3.4) and (3.5) indicate that the replacement of labor taxes by environmental taxes on consumption widens the wedge between the before- and real after-tax wages (i.e. $\tilde{P}_l^f - \tilde{P}_l^n > 0$) on account of this negative effect on the tax base. Thus, if it needs to maintain overall tax revenues, the government is unable to reduce the labor tax sufficiently to offset the adverse effect of the higher environmental tax on the real after-tax wage. The resulting lower income from an additional unit of work reduces labor supply and, therefore, employment.

Parameters impacting the adverse employment effect

The magnitude of the adverse employment effect depends, apart from the uncompensated wage elasticity of labor supply, on both the initial environmental tax and the substitution elasticity in consumption between the polluting and non-polluting commodities. A higher initial tax rate strengthens the adverse revenue effects of the erosion of the base of the environmental tax, thereby reducing the room to cut the tax on labor income. This negatively affects after-tax wages and, therefore, harms the incentives to supply labor.

A higher substitution elasticity between polluting and non-polluting commodities raises not only the positive effects on environmental quality, but also the adverse effects on the incentives to supply labor. Intuitively, it strengthens the erosion of the base of the environmental tax, thereby limiting the scope to reduce taxes on labor income. Thus, a fundamental trade-off exists between positive environmental effects and adverse effects on the incentives to supply labor; the more substantial the beneficial environmental effects of a given tax on polluting

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[10] In the absence of environmental externalities, the optimal commodity tax structure would not differentiate between polluting and non-polluting commodities because the utility structure implies that the substitution elasticities between the untaxed commodity (leisure) and the two consumption commodities are equal. Indeed, the effect of consumption taxes on the base of the labor tax depends only on the average tax rate on consumption and not on how the overall tax burden is distributed over the two commodities.

consumption commodities are, the larger become the adverse effects on the incentives to supply labor.

Another important determinant of the adverse employment effect is the size of the public sector, which is closely related to the term R in the denominator of the reduced form. In particular, a larger revenue requirement due to a higher level of public spending implies that an environmental tax yields a larger adverse effect on employment. The reason is that the environmental tax becomes a less effective instrument for raising additional revenue if a larger public sector requires higher initial tax rates on labor and the polluting commodities. Intuitively, how effective higher environmental tax rates are in raising additional public revenues depends on the balance between, on the one hand, larger revenues from a given tax base and, on the other hand, smaller revenues on account of behavioral changes that erode the tax bases of pre-existing taxes.

The relative importance of the second effect (i.e. the tax-base effect) on revenues depends on both the size of the initial tax rates and the strength of the behavioral changes. In the case of a higher environmental tax, two behavioral changes shrink the tax base. First, as discussed above, a change in the composition of the consumption basket away from the polluting commodity erodes the base of the environmental tax. The revenue impact of this first behavioral change depends on the initial tax rate on the polluting consumption commodity.

The second behavioral effect reducing the tax base is the adverse employment effect. In particular, a larger term R (corresponding to higher initial tax rates) implies that a fall in employment reduces revenues from labor taxes and environmental taxes more substantially. Consequently, in the presence of a larger public sector, which is associated with a larger value for R, higher environmental taxes are less effective in raising additional public revenue because they harm employment and, therefore, erode the bases of higher pre-existing taxes. This adversely affects revenue and further diminishes the scope for reducing taxes on labor, thereby negatively affecting labor-supply incentives. [11]

Welfare effects

The overall welfare effects are given in table 4. In the 'first-best' case, in which there is no need to finance public spending through distortionary taxation (i.e.

[11] The model is unstable if the adverse revenue effect of an eroding tax base exceeds the positive revenue effect of a higher tax rate on a given tax base. In that case, the government is beyond the top of the Laffer curve of the environmental tax and det $= Z - \theta_{ll} R < 0$. Hence, the tax base of the labor tax, Z, which captures the revenue-raising capacity of a (direct or indirect) tax on labor income under the assumption of no behavioral changes, is smaller than the term $\theta_{ll} R$, which represents the effect of behavioral changes in labor supply on the tax revenues from the existing tax system.

$t_l = 0$), the environmental tax levied on households should be set so that it fully internalizes the external effects of pollution. This yields the following optimality condition: [12]

$$\frac{t_d}{P_d^h} = \frac{\alpha_q}{\alpha_{dh}} \eta \theta_d. \tag{4.1}$$

If the environmental tax is set at this level, a marginal decline in the environmental tax would not affect overall welfare if the government requires only the Pigovian tax to finance its spending, so that the labor-market distortion is absent (i.e. $t_l = 0$). The adverse welfare effects associated with a dirtier environment would exactly offset the positive effects on welfare due to an expansion of the tax base. In this 'first-best' case, labor supply and employment would rise as a consequence of the lower environmental tax. However, without an initial (distortionary) direct tax on labor, higher employment would not raise welfare because the social opportunity costs of additional employment would exactly offset the social benefits.

In the case where financing of public spending requires a distortionary tax on labor, in contrast, overall welfare would rise if the government would marginally reduce the environmental tax below the level that fully internalizes the external effects of pollution (and would, at the same time, raise the tax rate on labor, t_l, to offset the revenue losses). Intuitively, in the first-best optimum, the environmental benefits exactly balance the costs of the eroding tax base of the environmental tax itself. In a 'second-best' case, in which distortionary taxes are required to raise public revenue, however, one should examine not only how the environmental tax impacts overall tax revenue through its effect on its own base, but also how such a tax affects overall revenue by impacting the bases of other taxes, and thereby the capacity of the rest of the tax system to raise revenue. In particular, in the presence of a distortionary tax on labor, the substitution of an environmental tax for a distortionary labor tax erodes the tax base of the labor tax because employment declines. The environmental tax thus reduces the capacity of the tax system to yield public revenues over and above the revenues from the environmental taxes themselves. Hence, reducing the environmental tax below its 'first-best' level and replacing the revenues by labor taxation would raise welfare because it would alleviate the distortions associated with the financing of public goods. Compared to the 'first-best' case, therefore, the optimal environmental tax would fall if a distortionary tax on labor were needed to finance public spending. Indeed, a Pigovian tax, which is set at a level to fully internalize the environmental damage, is suboptimal in the presence of distortionary taxes aimed at raising revenue. This argument resembles that of Buchanan (1972), who argued that a Pigovian tax may

[12] This expression does not provide for an explicit solution for the optimal environmental tax because the terms at the right-hand side of (4.1) depend on the tax.

not be optimal if a polluting commodity is supplied by a monopolist. Whereas Buchanan dealt with the market imperfection of a monopoly power, this paper focusses on a tax distortion in the labor market. In both cases, however, market imperfections tend to reduce the optimal size of the environmental tax as compared to the 'first-best' case in which distortions other than the environmental externalities are absent.

If the environmental tax is set below its 'first-best' optimum (i.e. the right-hand side of (4.1) exceeds the left-hand side), a higher tax yields ambiguous welfare effects because it reduces not only pollution but also employment. On the one hand, a higher environmental tax enhances welfare by reducing pollution and alleviating the environmental distortion. On the other hand, however, the tax harms welfare by reducing employment, thereby worsening the labor-market distortion. Indeed, this is a classic second-best result; reducing one distortion in an economy with remaining distortions does not necessarily yield positive welfare effects.

4.2. Tax on the polluting input into production

Effects on employment

As regards the environmental tax levied on inputs into production, the first row in the second column of Table 3 reveals that also this tax harms employment if the initial tax is positive (i.e. $\beta_e > 0$). In fact, the reduced form for employment resembles that corresponding to an environmental tax on households; both the initial rate of the environmental tax and the revenue requirement raise the adverse employment effect. Here, the relevant substitution elasticity, σ_l^*, is a composite of the substitution elasticities in production:

$$\sigma_l^* = \frac{\alpha_k}{\alpha_k + \alpha_{ef}} \sigma_n + \frac{\alpha_{ef}}{\alpha_k + \alpha_{ef}} \frac{\sigma_l}{\alpha_{lf}}. \tag{4.2}$$

Just as in the case of a tax on households, the negative effect on employment originates in a fall in the real after-tax wage and the associated adverse effects on the incentives to supply labor. The reason for the decline in the marginal income from work is that the production tax reduces the demand for polluting inputs. This adversely affects real labor income through two channels. First, as explained in the previous section, it decreases the marginal productivity of labor and, therefore, the before-tax wage. Secondly, the higher environmental tax erodes its own base. If the initial tax rate on the polluting input is positive, the smaller tax base reduces revenue, thereby producing a negative tax-base effect (i.e. $\tilde{b}^t < 0$). Accordingly, given the constraint of revenue neutrality, the government cannot cut the tax rate on labor income sufficiently to fully offset the adverse effect of the fall in before-tax wages on the after-tax wage. Indeed, expressions (3.7) and (3.8) reveal that the after-tax wage declines if the tax base of the initial tax system shrinks (i.e.

$\tilde{b}^t < 0$).[13] High initial tax rates (i.e. a high value of R) exacerbate the adverse revenue effects of the fall in employment.

Welfare effects

The welfare effects of the production tax are contained in Table 4. Just as in the case of an environmental tax on consumption, a trade-off exists between environmental benefits and the worsening of the tax distortion in the labor market on account of a smaller tax base. The effect on the labor-market distortion is small if firms have little scope to substitute capital and labor for polluting inputs (i.e. σ_l^* is small). In that case, however, also the environmental benefits are small. A fundamental conflict thus exists between the objectives of improving environmental quality and minimizing the costs of financing public spending.

The relative importance of the effect on the labor-market distortion depends importantly on the overall revenue requirement. Accordingly, a higher level of public spending reduces the welfare gains from switching from labor to environmental taxation. Indeed, such a change in the tax mix may harm welfare, even though the initial environmental tax is below the level that fully internalizes the external costs of pollution (i.e. $t_e/P_e^f) < \eta\theta_e(\alpha_q/\alpha_{ef})$.

4.3. Environmental taxes: No double dividend

These results imply that the ‘double-dividend’ story fails. Pre-existing tax distortions in the labor market reduce rather than enhance the attractiveness of environmental policy, in general, and of a heavy reliance on environmental taxes, in particular. The fundamental reason is that the environment is a collective good; all residents benefit – irrespective of the amount of labor they supply. Indeed, an improvement in the environment can be interpreted as an increase in the supply of collective goods. All public goods, including the cleaner environment, are ultimately paid for by the immobile production factor, labor. Hence, the costs associated with a cleaner environment reduce the incentives to supply labor at the margin, thereby contracting the base of the labor tax and raising the marginal efficiency costs of financing (other) public spending.

In particular, environmental taxes reduce after-tax wages on two accounts. First, labor pays for the public goods supplied by the government, as all taxes required to finance public spending are ultimately borne by labor. Second, from the point of view of financing public spending with the least costs to real after-tax

[13] Accordingly, directly taxing labor yields a higher after-tax wage than taxing labor indirectly by taxing the polluting inputs into production. The reason is that the tax on the mobile inputs is borne by immobile labor. Furthermore, unlike a direct tax on labor income, the input tax distorts the production process, at least if one abstracts from the environmental benefits. This result is closely related to that derived by Diamond and Mirrlees (1971). They show that aggregate production efficiency is desirable in the presence of optimal commodity taxation. See also Gordon (1986).

wages, environmental taxes do not tax labor 'efficiently;' they not only reduce the after-tax wage, but also 'distort' either the composition of the consumption basket or the production process. Although these 'distortions' reduce the real after-tax income from work, they also do contribute to a higher environmental quality. The positive welfare effects associated with higher environmental quality, however, are public and independent of labor supply. In this way, the costs of improving the environment are borne by marginal labor supply. Thus, labor pays not only for the public goods provided through the public budget but also for the costs incurred by the private sector in improving environmental quality. Indeed, the use of environmental taxes implies that the private sector, in fact, provides the collective good of the environment. Accordingly, the costs of 'producing' the collective good of higher environmental quality do not feature on the government budget and are, therefore, 'hidden.'

These results are consistent with the optimal-tax results derived in a partial-equilibrium framework by Sandmo (1975). [14] This study analyses the case of a government employing its tax system to simultaneously achieve two objectives: first, to satisfy its revenue requirement and, second, to internalize external effects. It derives the optimal-tax rate for an externality-creating commodity as the weighted average of two terms: first, the marginal social damage of the polluting commodity and, second, an inverse elasticity formula familiar from the theory of optimal taxation. The weight of the marginal social damage decreases as the revenue requirement increases. Intuitively, an environmental tax reduces pollution by inducing taxpayers to avoid taxes. Tax avoidance not only reduces pollution, however, but also requires the government to levy higher distortionary taxes to finance its own spending. Accordingly, the larger the government's revenue needs are (and hence the higher the distortionary taxes need to be), the less the government can afford tax differentiation aimed at environmental protection. Indeed, marginal tax revenue becomes more valuable if the government has to rely on distortionary taxes to finance its spending. The optimal environmental tax balances the social costs of pollution against the social benefits from additional tax revenues. Therefore, the higher the social value attached to tax revenue, the higher the marginal social costs of pollution have to be to justify environmental taxes. There exists thus a basic conflict between using the tax system to achieve the twin objectives of raising revenue and improving environmental quality.

5. Extensions

The analysis in this paper could be extended in several directions. An extension favorable to the double-dividend argument, at least from the point of view of

[14] See also Bovenberg and Van der Ploeg (1994).

national welfare, would be to relax the small-economy assumptions by reducing the degree of international mobility of commodities, polluting inputs and capital. This would enable the country to shift some of the burden of the environmental taxes onto the foreign country by changing the terms of trade. From the point of view of global welfare, this would merely amount to redistributing income away from foreigners toward domestic residents. Whether this would actually improve global efficiency would depend on the distortions and behavioral responses, both domestically and abroad [15].

Similarly, if the country were in a position to affect the world interest rate, an environmental tax on production may be borne in part by savers. Whether this would improve overall efficiency would depend on, among other things, both the elasticity of saving and the existing taxes on capital income. An analysis of these issues would require a dynamic model with capital accumulation. Modelling overlapping generations within such an intertemporal framework would allow one to deal with issues of intertemporal efficiency and intergenerational equity related to both the timing of taxes and lags between emissions and environmental quality.

Another extension in favor of the double dividend is contained in Bovenberg and De Mooij (1993) who distinguish two sources of household income: labor and transfer incomes. Hence, the economic burden associated with a cleaner environment can be shifted towards transfer incomes. In that case, efficiency may improve and thus a double dividend be realized. However, the income distribution between households is likely to become less equitable. Hence, there is a fundamental trade-off between equity and efficiency.

Other extensions would be unfavorable to the double-dividend argument. To illustrate, other labor-market imperfections, such as real-wage rigidities, would tend to raise the costs of environmental taxes. Furthermore, the quality of the environment could be made complementary to leisure. In that case, an improvement in environmental quality would reduce the supply of labor through another channel.

6. Conclusions

This paper suggests that second-best considerations play an important role in setting environmental policy, in general, and in implementing environmental taxes, in particular. Whereas Buchanan (1972) pointed this out for the case of a

[15] It is highly unlikely that the industrialized countries would be able to shift the costs of the environmental policies to the LDCs. In contrast, the industrialized countries most likely would have to bribe the LDCs to participate in international agreements on global and continental environmental problems. Hence, workers in industrialized countries are likely to bear a substantial part of the burden of cutting pollution in not only the industrial countries but also the LDCs.

monopolist supplying a polluting commodity, this paper explores how tax distortions associated with the financing of public spending impact the effects of environmental policy. It demonstrates that an increase in environmental taxes toward a level that fully internalizes the social costs of pollution may no longer be welfare improving if the government requires distortionary taxes to finance its spending. Oates and Schwab (1988) also highlight the interaction between environmental policy and tax distortions. They show that, from the point of view of global efficiency, communities that require high distortionary taxes on mobile capital should set relatively lax environmental standards. This would serve to offset the distortions introduced by fiscal policy. [16]

High estimates for the marginal efficiency costs of the existing tax system are sometimes used in support of environmental taxes (see e.g. Pearce (1991) and Oates (1991)). This paper has shown that such arguments are misleading because they ignore the costs of environmental taxes in terms of exacerbating the pre-existing distortions associated with the financing of public spending through distortionary taxation. In particular, environmental taxes typically render the tax structure a less efficient instrument for raising revenue and, therefore, increase the welfare costs of financing public spending. The additional costs of environmental taxes due to less efficient revenue-raising are likely to be especially high if the marginal efficiency costs of the existing tax system are substantial. Therefore, the higher the efficiency costs of the existing tax structure are, the higher the environmental benefits need to be in order to justify the additional costs of environmental taxes in terms of a less efficient mechanism for financing public spending. Indeed, high estimates for the efficiency costs of existing taxes *weaken* rather than *strengthen* the case for environmental taxation.

A higher priority for the public good of environmental quality is likely to require a heavier reliance on environmental taxes. This change in the tax structure, however, typically raises the marginal efficiency costs of financing public spending, especially if environmental taxes are successful in reducing pollution. Intuitively, environmental taxes increase the supply of environmental services, thus boosting the overall supply of public goods, and therefore raising the marginal costs of public goods provision more generally. In this way, the public good of a cleaner natural environment directly competes with other public goods. [17] Indeed, the services from the environmental quality are not free. On the contrary, since

[16] In the context of policy competition, Oates and Schwab (1988) also found that competing jurisdictions set inefficiently low environmental standards if these communities have to rely on a tax on mobile capital to finance their public spending.

[17] The condition of the natural environment in Eastern Europe and the former Soviet Union provides a dramatic example of this. In these countries, a large public sector has crowded out a clean environment.

these services are public, they are expensive – especially in those countries with large public sectors that require high distortionary taxes.

Notation

$Y =$	supply of the domestic commodity
$L_d =$	domestic labor demand
$K =$	domestic demand for capital services
$E =$	domestic demand for polluting inputs
$P_y =$	price of commodity Y
$P_l^f =$	before-tax wage rate
$t_l =$	ad valorem tax rate on labor income
$P_l =$	after-tax wage rate
$P_e^f =$	price of polluting inputs faced by firms
$P_e =$	market price of polluting inputs
$t_e =$	specific tax rate on polluting inputs
$r =$	rate of return on capital
$V =$	household demand for leisure
$\lambda =$	marginal (private) utility of income
$L_s =$	labor supply
$M =$	environmental quality
$Q =$	sub-utility from consuming private commodities
$P_q =$	shadow price of Q
$D =$	consumption of the polluting commodity by households
$C =$	consumption of the 'clean' commodity by households
$P_c =$	price of the non-polluting consumption commodity
$P_d^h =$	price of the polluting consumption commodity faced by households
$P_d =$	market price of the polluting consumption commodity
$t_e =$	tax rate on the polluting consumption commodity
$G =$	public demand in real terms
$P_g =$	price of public goods

Appendix A: Analytical solution of the reduced form equations

We write Eq. (II.17) for the case where the prices of tradables do not change and $\tilde{G} = 0$:

$$\tilde{Y} = \alpha_d \tilde{D} + \alpha_e \tilde{E} + \alpha_k \tilde{K} + \alpha_c \tilde{C}. \tag{A.1}$$

Using (A.1) and the equation for the supply of goods (II.1), one can eliminate $\tilde{Y}$:

$$\alpha_{lf} \tilde{L}_d = -\beta_e \tilde{E} + \alpha_d \tilde{D} + \alpha_c \tilde{C}, \tag{A.2}$$

where we have used that

$$\alpha_{ef} = \alpha_e + \beta_e. \tag{A.3}$$

Eq. (A.2) can be interpreted as an expression for labor demand. We now express the three endogenous variables at the right-hand side of Eq. (A.2) in terms of $\tilde{L}$ and $\tilde{P}_l^n$.

To find the expression for $\tilde{E}$, we first subtract (II.2) from (II.4) and use (II.7) to eliminate $\tilde{P}_e^f$. If the prices for tradables do not change, this yields

$$\tilde{E} = \tilde{L} + \sigma_l \tilde{P}_l^f - \left[\frac{\alpha_k}{\alpha_{ef} + \alpha_k} \sigma_n + \frac{\alpha_{ef}}{\alpha_{ef} + \alpha_k} \sigma_l \right] \tilde{t}_e. \tag{A.4}$$

Substituting (II.7) into the non-profit condition (II.5) yields

$$\tilde{P}_l^f = -\frac{\alpha_{ef}}{\alpha_{lf}} \tilde{t}_e. \tag{A.5}$$

Substituting (A.5) into (A.4) to eliminate $\tilde{P}_l^f$, one derives

$$\tilde{E} = \tilde{L} - \sigma_l^* \tilde{t}_e, \tag{A.6}$$

where

$$\sigma_l^* = \left[\frac{\alpha_k}{\alpha_k + \alpha_{ef}} \sigma_n + \frac{\alpha_{ef}}{\alpha_k + \alpha_{ef}} \frac{\sigma_l}{\alpha_{lf}} \right]. \tag{A.7}$$

To find $\tilde{C}$ and $\tilde{D}$ in terms of $\tilde{P}_l^n$ and $\tilde{L}$, we eliminate $\tilde{Q}$ in (II.10) and (II.11) by substituting the household budget constraint (II.8) and use (II.13) for $\tilde{P}_l^n$:

$$\tilde{C} = \tilde{P}_l^n + \tilde{L} + (1 - \phi_c) \sigma_q \tilde{t}_d, \tag{A.8}$$

$$\tilde{D} = \tilde{P}_l^n + \tilde{L} - \phi_c \sigma_q \tilde{t}_d. \tag{A.9}$$

Here, we have used the price equations (II.12) and (II.14) to rewrite $\tilde{P}_q$ and $\tilde{P}_d^h$ in terms of $\tilde{t}_d$. Substituting (A.6), (A.8), and (A.9) into (A.2), one derives:

$$\alpha_{lf} \tilde{L} = [\alpha_d + \alpha_c] \left[\tilde{P}_l^n + \tilde{L} \right] - \beta_e \tilde{L} + \beta_e \sigma_l^* \tilde{t}_e + [(1 - \phi_c) \alpha_c - \phi_c \alpha_d] \sigma_q \tilde{t}_d \tag{A.10}$$

We can write the last term in square brackets at the right-hand side of (A.10) as

$$(1 - \phi_c) \alpha_c - \phi_c \alpha_d = \frac{P_d^h D}{P_q Q} \frac{P_c C}{P_y Y} - \frac{P_c C}{P_q Q} \frac{P_d D}{P_y Y} = \frac{P_c C}{P_q Q} \frac{t_d D}{P_y Y} = \phi_c \beta_d. \tag{A.11}$$

Using (A.11), we can now rewrite labor demand in (A.10) as

$$R\tilde{L} - Z\tilde{P}_l^n = \phi_c \beta_d \sigma_q \tilde{t}_d + \beta_e \sigma_l^* \tilde{t}_e, \tag{A.12}$$

where

$$Z = \alpha_d + \alpha_c, \tag{A.13}$$

$$R = \alpha_{lf} + \beta_e - Z = \beta_l + \beta_e + \beta_d. \tag{A.14}$$

The term Z in (A.13) measures real after-tax expenditure of households as a result of additional employment. R in (A.14) represents the marginal size of the public sector, i.e. the additional tax revenue due to an additional unit of employment.

Labor supply (II.9) yields

$$\tilde{L}_s = \theta_{ll} \tilde{P}_l^n. \tag{A.15}$$

We write (A.12) and (A.15) in matrix notation as

$$\begin{pmatrix} R & -Z \\ 1 & -\theta_{ll} \end{pmatrix} \begin{pmatrix} \tilde{L} \\ \tilde{P}_l^n \end{pmatrix} = \begin{pmatrix} \phi_c \beta_d \sigma_q & \beta_e \sigma_l^* \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \tilde{t}_d \\ \tilde{t}_e \end{pmatrix}. \tag{A.16}$$

We can solve for the endogenous variables by inverting the matrix on the left-hand side of (A.16):

$$\det \begin{pmatrix} \tilde{L} \\ \tilde{P}_l^n \end{pmatrix} = \begin{pmatrix} -\theta_{ll} & Z \\ -1 & R \end{pmatrix} \begin{pmatrix} \phi_c \beta_d \sigma_q & \beta_e \sigma_l^* \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \tilde{t}_d \\ \tilde{t}_e \end{pmatrix}, \tag{A.17}$$

$$\det = Z - \theta_{ll} R. \tag{A.18}$$

The term 'det' must be positive for the equilibrium to be stable. This determinant consists of two elements. The first term on the right-hand side of (A.18) can be interpreted as the real value of after-tax wage income. This net private income constitutes the tax base for the public sector. The second term stands for the impact of higher real after-tax wages on tax revenues through its behavioral effect on labor supply and, therefore, the base of the tax system. If θ_{ll} and R are large relative to Z, the economy may be unstable. Intuitively, a lower real after-tax wage may turn the economy into a downward spiral. This is because lower after-tax wages reduce the incentive to supply labor, thereby reducing tax revenues through an erosion of the tax base. Hence, the tax on labor needs to rise in order to meet the revenue constraint. This further reduces net wages and, therefore, the tax base. The instability due to a negative slope of the 'Laffer curve', can occur only if the public sector is large relative to net private income (i.e. R is large relative to Z). Moreover, private behavior should be sensitive to tax incentives (i.e. θ_{ll} is large).

The reduced form equations for $\tilde{P}_l^n$ and $\tilde{L}$ can now be computed from (A.17):

$$\det \tilde{L} = -\theta_{ll} \beta_d \phi_c \sigma_q \tilde{t}_d - \theta_{ll} \beta_e \sigma_l^* \tilde{t}_e, \tag{A.19}$$

$$\det \tilde{P}_l^n = -\beta_d \phi_c \sigma_q \tilde{t}_d - \beta_e \sigma_l^* \tilde{t}_e. \tag{A.20}$$

The other reduced-form equations can now be derived. For $\tilde{E}$ one can find the reduced-form equation from (A.6), by substituting (A.19) for $\tilde{L}$.

We use (II.12), (II.13), and (II.14) to find the reduced form for $\tilde{P}_l$:

$$\tilde{P}_l = \tilde{P}_l^n + (1 - \phi_c)\tilde{t}_d. \tag{A.21}$$

In order to express $\tilde{D}$ and $\tilde{C}$ in terms of the exogenous variables, one substitutes (A.19) and (A.20) into (A.8) and (A.9) respectively.

For the endogenous tax rate on labor, $\tilde{t}_l$, we use (II.6):

$$\tilde{t}_l = \tilde{P}_l^f - \tilde{P}_l \tag{A.22}$$

Substituting $\tilde{P}_l^f$ from (A.5) and the reduced form for $\tilde{P}_l$ into (A.22), one arrives at the reduced-form equation for $\tilde{t}_l$.

The demand for capital services can be rewritten by subtracting (II.3) from (II.2). If we substitute (II.7) and (A.5) for $\tilde{P}_e^f$ and $\tilde{P}_l^f$ respectively, we find

$$\tilde{K} = \tilde{L} + (\sigma_n - \sigma_l^*)\tilde{t}_e. \tag{A.23}$$

By sustituting (A.19) into (A.23), one arrives at the reduced form for $\tilde{K}$.

Finally, substituting (A.5) and (II.7) into (II.2), we derive the following equation for $\tilde{Y}$:

$$\tilde{Y} = \tilde{L} - \frac{\alpha_{ef}}{\alpha_{lf}}\sigma_l\tilde{t}_e. \tag{A.24}$$

One arrives at the reduced form for $\tilde{Y}$ by substituting (A.19) into (A.24).

Appendix B: The excess burden

In analogy of Keller (1980), we compute the 'marginal' excess burden as the compensating variation, which is defined as the transfer necessary to maintain, after a policy change, utility at its original level. For small changes, the compensating variation equals the equivalent variation.

Accordingly, we find the compensating transfer such that, after the policy shock, utility is unchanged compared to the initial equilibrium, i.e.

$$0 = \mathrm{d}U = \frac{\partial U}{\partial V}\mathrm{d}V + \frac{\partial U}{\partial C}\mathrm{d}C + \frac{\partial U}{\partial D}\mathrm{d}D + \frac{\partial U}{\partial M}\mathrm{d}M. \tag{B.1}$$

Utility maximization implies that the partial derivatives at the right-hand side of (B.1) are equal to λ, the Lagrange multiplier corresponding to the budget constraint, times the corresponding price (see (I.10), (I.11) and (I.12)). Hence, we write (B.1) as

$$-\lambda P_l \mathrm{d}L + \lambda P_c \mathrm{d}C + \lambda P_d^h \mathrm{d}D + \frac{\partial U}{\partial M}\mathrm{d}M = 0, \tag{B.2}$$

where we have used $\mathrm{d}L = -\mathrm{d}V$. From the household budget constraint (I.9) we have

$$L\mathrm{d}P_l + P_l\mathrm{d}L + \mathrm{d}\beta = C\mathrm{d}P_c + P_c\mathrm{d}C + D\mathrm{d}P_d^h + P_d^h\mathrm{d}D. \tag{B.3}$$

Here $\mathrm{d}\beta$ is the compensating variation. Substituting (B.2) into (B.3), yields for $\mathrm{d}\beta$:

$$\mathrm{d}\beta = -L\mathrm{d}P_l + C\mathrm{d}P_c + D\mathrm{d}P_d^h - \frac{\partial U}{\partial M}\frac{\mathrm{d}M}{\lambda}. \tag{B.4}$$

We define the marginal excess burden, $\tilde{\beta}$, as the compensating variation, $\mathrm{d}\beta$, relative to household income, $P_lL = P_qQ$. This yields the following expression for the marginal excess burden:

$$\tilde{\beta} = -\tilde{P}_l + (1-\phi_c)\tilde{t}_d - \left(\frac{\partial U/\partial M}{\partial U/\partial Q}\right)\frac{M}{Q}\tilde{M}, \tag{B.5}$$

where we have used (II.14), $\partial U/\partial Q = \lambda P_q$, and $\mathrm{d}P_c = 0$. Alternatively, using (II.13), (II.18) and the definition of η, we can write the marginal excess burden as

$$\tilde{\beta} = -\tilde{P}_l^n + \eta\left(\theta_d\tilde{D} + \theta_e\tilde{E}\right). \tag{B.6}$$

In order to derive the expression for the marginal excess burden in (2.1), we use the public budget constraint (II.15) with $\tilde{P}_g = \tilde{G} = 0$:

$$\beta_l\tilde{L} + \beta_e\tilde{E} + \beta_d\tilde{D} = -\beta_l\tilde{P}_l - \alpha_{ef}\tilde{t}_e - \alpha_{dh}\tilde{t}_d - \alpha_{lf}\tilde{t}_l. \tag{B.7}$$

From (II.5), (II.6) and (II.7), we derive

$$\alpha_{lf}\tilde{t}_l = -\alpha_{lf}\tilde{P}_l - \alpha_{ef}\tilde{t}_e. \tag{B.8}$$

Substituting (B.8) into (B.7), using (II.13), and dividing both sides by P_q, one finds

$$\tilde{P}_l^n = \frac{\beta_l}{\alpha_q}\tilde{L} + \frac{\beta_e}{\alpha_q}\tilde{E} + \frac{\beta_d}{\alpha_q}\tilde{D}. \tag{B.9}$$

According to (2.4) the right-hand side of (B.9) equals $\tilde{b}^t$. Hence, (2.5) holds.

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