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CONSEQUENCES OF ENVIRONMENTAL TAX REFORM FOR INVOLUNTARY UNEMPLOYMENT AND WELFARE

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Working Paper No. 56

UNIVERSITY OF MUNICH

CES

Working Paper Series

CES Working Paper Series

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We benefited from helpful discussions with George Johnson.

CES Working Paper No. 56
February 1994

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Abstract

We investigate the consequences of environmental tax reform, i. e. raising the tax rate on polluting factors of production (resources) and using the proceeds to reduce the tax rate on labour, for employment, involuntary unemployment, and the various components of social welfare including environmental quality. The framework of analysis is a small open economy with rationing of labour supply due to a rigid consumer wage. If substitution between labour and resources is easy, the production share of the fixed factor is large, and the initial tax rates on resources and profits are small, environmental tax reform yields a double dividend in the sense that both environmental quality and employment increase. If the initial tax system is suboptimal with a neglible tax on resources, profits rise as well. Hence, a triple dividend occurs.

JEL code: E60, H21, Q3

Keywords: Tax reform, revenue target, environmental quality, resources, dirt tax, labour tax, factor substitution, involuntary unemployment, double dividend, triple dividend, green-red reform.

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CONTENTS

1 Introduction

One of the most pressing problems facing many countries today is the rapid degradation of the natural environment. The most natural response is to charge polluters a price for the damage they inflict on the natural environment. At the same time, many Western societies suffer also from high levels of involuntary unemployment. Many economists therefore argue that the public revenues generated by environmental taxes should be used to reduce the distortionary tax rate on labour. Such an 'environmental' tax reform should kill two birds with one stone; namely, first, improve the quality of the natural environment, and, second, combat involuntary unemployment.

This paper investigates how an environmental tax reform impacts involuntary unemployment and welfare in a setting with a rigid consumer wage.[1] We find that introducing a small dirt tax typically yields a triple dividend in the sense that environmental quality, employment and after-tax income from the fixed factor rise. In that case, private consumption and private utility rise while the level of involuntary unemployment falls. However, if the initial resource tax is already relatively large, a double or a triple dividend is less likely to occur. If the resource tax is at its optimal level, a double dividend (with expanding employment) may still materialise if the production share of the fixed factor is large and substitution between resources and labour is easy. In that case, the fixed factor pays for the higher quality of the environment.

Section 2 derives the own and cross price elasticities for factor demands under three different separable production functions. Assuming that the initial tax system is not necessariliy optimal, section 3 explores the impact of an environmental tax reform on a number of macroeconomic variables. The consequences for the various components of welfare are examined in section 4. This section also discusses the optimal tax rates. Section 5 analyses the implications of more environmental concern under the assumption that the economy is initially at an optimum. Section 6 briefly investigates the effects of a green-red tax reform of the public sector, i.e. a reform in which the revenues generated by higher environmental taxes are used to finance additional public spending. Section 7 concludes with a summary of the main results.

2 Factor demands

Firms face a concave production function $Y=F(L,R,H)$ with constant returns to scale,

[1] Marchaud, Pestieau and Wibaut (1984) also investigate tax reform under unemployment caused by a rigid consumer wage. We extend their work by allowing for environmental externalities. Bovenberg and van der Ploeg (1993a) focus at *optimal* taxation rather than at tax *reform* in a situation with environmental externalities and involuntary unemployment due to real wage rigidity; they investigate also the optimal provision of public goods.

where L, R and H denote, respectively, the use of labour, resources and the fixed factor in production, and Y stands for output. The use of resources in production pollutes the natural environment. Labour and the fixed factor, in contrast, are clean factors of production. Firms maximise profits under perfect competition. Accordingly, they take the producer wage w_P, the producer resource cost q_P, and the producer price of the fixed factor p_H as exogenously given. This yields $F_L = w_P$ and $F_R = q_P$, which in turn gives rise to the factor demand functions:

$$L = H\, l(w_P,q_P), \quad R = H\, r(w_P,q_P) \tag{1}$$

where $l_w \equiv \partial l/\partial w_P = F_{RR}/\Delta \leq 0$, $r_q \equiv \partial r/\partial q_P = F_{LL}/\Delta \leq 0$, $l_q \equiv \partial l/\partial q_P = r_w \equiv \partial r/\partial w_P = -F_{LR}/\Delta$ with $\Delta \equiv F_{LL}F_{RR}-F_{LR}^2 > 0$. The corresponding factor price frontier follows from $p_H = F_H$ and (1):

$$p_H = \pi(w_P,q_P) \tag{2}$$

with $\pi_w \equiv \partial\pi/\partial w_P = -L/H < 0$ and $\pi_q \equiv \partial\pi/\partial q_P = -R/H < 0$. We refer to income from the fixed factor as profit income, i.e. $\Pi \equiv F(L,R,H)-w_PL-q_PR = \pi(w_P,q_P)H$, where Π denotes pre-tax profits.

The demand for labour (resources), conditional on the level of the fixed factor, falls if the user cost of labour (resources) rises. A higher producer cost of resources raises the demand for labour if the substitution effect dominates the output effect, i.e. if labour and resources are non-cooperative production factors ($F_{LR} < 0$). In that case, a higher producer wage boosts the demand for resources. However, if the income effect dominates the substitution effect ($F_{LR} > 0$), the effect of wages on resource demand is negative. Profit income declines if the producer wage or the user cost of resources rises.

We denote loglinear deviations by a tilde (e.g. $\tilde{L} \equiv dL/L$), unless indicated otherwise. Hence, expressions (1) and (2) become:

$$\tilde{L} = \tilde{H} - \epsilon_{Lw}\,\tilde{w}_P - \epsilon_{Lq}\,\tilde{q}_P, \quad \tilde{R} = \tilde{H} - \epsilon_{Rq}\,\tilde{q}_P - \epsilon_{Rw}\,\tilde{w}_P \tag{1'}$$

$$\omega_H\,\tilde{p}_H = -\omega_L\,\tilde{w}_P - \omega_R\,\tilde{q}_P, \quad \omega_H+\omega_L+\omega_R = 1 \tag{2'}$$

where $\epsilon_{Lw} \equiv -w_P l_w/l \geq 0$, $\epsilon_{Lq} \equiv -q_P l_q/l$, $\epsilon_{Rq} \equiv -q_P r_q/r \geq 0$, $\epsilon_{Rw} \equiv -w_P r_w/r$ stand for the factor demand elasticities, and $\omega_H \equiv p_H H/Y$, $\omega_L \equiv w_P L/Y$, $\omega_R \equiv q_P R/Y$ denote the production shares of the fixed factor, resources and labour, respectively. Expression (2′) is equivalent to the familiar zero-profit condition. To obtain a better understanding of what determines the own and cross price

elasticities of factor demand, the next three sub-sections consider three types of separable production functions in turn. Table 1 summarises the results.

2.1 Resources separable

If resources are separable from the other production factors, the production function may be written as $Y = F(Q(H,L),R)$ where the sub-production function Q(.) features constant returns to scale. Profit maximisation yields $Q_L/Q_H = w_P/p_H$ or $\tilde{L}-\tilde{H} = \sigma_{LH}(\tilde{p}_H-\tilde{w}_P)$, where $\sigma_{LH} \equiv d\log(L/H)/d\log(Q_H/Q_L)$ stands for Allen's elasticity of substitution between L and H. Using (2′) to eliminate $\tilde{p}_H$, we obtain $\epsilon_{Lw} = \sigma_{LH}(1-\omega_R)/\omega_H \geq 0$ and $\epsilon_{Lq} = \sigma_{LH}\omega_R/\omega_H \geq 0$. Symmetry yields $\epsilon_{Rw} = \sigma_{LH}\omega_L/\omega_H \geq 0$. Labour and resources are thus cooperative production factors (i.e. $F_{LR} \geq 0$) if resources are separable. Hence, the income effect dominates the substitution effect and the cross price elasticities ϵ_{Lq} and ϵ_{Rw} are non-negative.

Profit maximisation yields also $F_R/F_Q = q_P/p_Q$ or $\tilde{R}-\tilde{Q} = \sigma_R(\tilde{p}_Q-\tilde{q}_P)$, where σ_R denotes the elasticity of substitution between Q and R in F(.) and p_Q represents the ideal price index for the composite labour-resource input, Q. Using the expression $(1-\omega_R)\tilde{Q} = \omega_L\tilde{L} + \omega_H\tilde{H}$ with $\tilde{H} = 0$ and $(1-\omega_R)\tilde{p}_Q = \omega_L\tilde{w}_P + \omega_H\tilde{p}_H = -\omega_R\tilde{q}_P$ to eliminate $\tilde{Q}$ and $\tilde{p}_Q$, we obtain $\epsilon_{Rq} = (\sigma_R + \sigma_{LH}\omega_L\omega_R/\omega_H)/(1-\omega_R) \geq 0$.

Without substitution between labour and the fixed factor ($\sigma_{LH} = 0$), the own and cross price elasticities of labour demand are zero and labour demand is thus completely inelastic ($\tilde{L} = \tilde{H} = 0$). In addition, the demand for resources does not respond to changes in the producer wage ($\epsilon_{Rw} = 0$).

2.2 Labour separable

If labour is separable in production, i.e. $Y = F(Q(R,H),L)$, the derivation of the own and cross price elasticities of factor demand follows the same procedure as in sub-section 2.1. Table 1 contains the results, where σ_{RH} denotes the elasticity of substitution between R and H in the sub-production function Q(.) and σ_L represents the elasticity of substitution between L and the composite capital-resource input Q. Hence, as long as substitution between resources and the fixed factor is feasible (i.e. $\sigma_{RH} > 0$), labour and resources are cooperative production factors (i.e. ϵ_{Lq} and ϵ_{Rw} are positive). Without substitution between resources and the fixed factor ($\sigma_{RH} = 0$), the demand for resources is completely inelastic.

2.3 Fixed factor separable

If the fixed factor is separable, we have $Y = F(Q(L,R),H)$. A similar procedure as in sub-section 2.1 yields the factor demand elasticities presented in Table 1, where σ_{LR} stands for the

elasticity of substitution between L and R in the sub-production function Q(.) and σ_H denotes the elasticity of substitution between the fixed factor and the composite labour-resource input. With this specification, resources and labour are non-cooperative factors of production, i.e. ϵ_{Lq} and ϵ_{Rw} are negative, if the production share of the fixed factor (ω_H) is large, substitution between the labour-resource composite and the fixed factor is difficult (σ_H is small), and substitution between labour and resources is easy (σ_{LR} large).

3 Environmental tax reform

Resources are bought on a competitive global market at an exogenous price q. The government levies a dirt tax on resources t_R, so that the producer price of resources amounts to $q_P \equiv q(1+t_R)$. Labour supply is rationed due to a rigid and too high exogenous consumer wage w. The government charges producers a tax on labour at a rate t_L, so that the producer wage is $w_P = w(1+t_L)$. The government must achieve an exogenous revenue target to meet an exogenous level of public spending G. The public budget constraint is

$$t_L\, w\, L + t_R\, q\, R + \tau\, \Pi = G. \qquad (3)$$

Adding the government budget and the household budget constraint ($C = wL + (1-\tau)\Pi$) together and making use of the definition of profit income yields the budget for the economy as a whole, i.e. total spending by domestic households and the government C+G plus imports of resources qR must equal domestic production Y. Alternatively, value added Y-qR must match spending by households and the government. Yet another way of stating this equilibrium condition is that exports of final consumption goods Y-C-G must equal imports of natural resources.

An environmental tax reform consists of a marginal increase in the resource tax (i.e. $\tilde{t}_R \equiv dt_R/(1+t_R) > 0$) while the tax rate of labour adjusts to ensure that the government budget is balanced. The consequences of such a reform for the labour tax rate, employment, resource use, profit income, private consumption, output, private utility and environmental quality are presented in Table 2. The remainder of this section and section 4 derive the results presented in Table 2, and provide the intuition behind these various effects.

3.1 Shift from resource to labour taxation

Taking relative changes of the government budget (3) and using $\tilde{q} = \tilde{w} = 0$, we obtain:

$$(1-\tau)\,(\omega_L\, \tilde{t}_L + \omega_R\, \tilde{t}_R) + \theta_L \omega_L\, \tilde{L} + \theta_R \omega_R\, \tilde{R} = \omega_G\, \tilde{G} = 0 \qquad (3')$$

where $\tilde{t}_L \equiv dt_L/(1+t_L)$ and $\theta_i \equiv t_i/(1+t_i)$, i=L,R. The last two terms on the left-hand side of (3′) stand for the effects on public revenue of changes in the labour tax *base* and the resource tax *base*. The first term on the left-hand side of (3′) represents two effects. First, a higher labour tax *rate* and a higher resource tax *rate* boost public revenue. Second, the associated rise in the producer wage and user cost of resources depress profit income and thus reduce revenue from the profit tax. In fact, if all profits are taxed away, this term vanishes. The reason is that, with a rigid consumer wage and an exogenous world market price for resources, higher tax rates on labour and resource use are shifted towards profit income and hence, with a 100 per cent profit tax, towards the government.

Substituting the factor demands (1′) into (3′), using $\tilde{H} = 0$, $\tilde{w}_P = \tilde{t}_L$, $\tilde{q}_P = \tilde{t}_R$, and solving for $\tilde{t}_L$ yields:

$$\tilde{t}_L = -\,[(1-\tau)\omega_R - \theta_L \omega_L \epsilon_{Lq} - \theta_R \omega_R \epsilon_{Rq}]\; \tilde{t}_R/\Delta^* \qquad (4)$$

where $\Delta^* \equiv (1-\tau)\omega_L - \theta_L \omega_L \epsilon_{Lw} - \theta_R \omega_R \epsilon_{Rw}$. We assume that in the initial equilibrium the economy is on the upward-sloping parts of the Laffer curves for both the labour tax and the resource tax. Hence, $\Delta^* > 0$ and the environmental tax reform implies a fall in the tax rate on labour ($\tilde{t}_L < 0$). The additional public revenues generated by a higher dirt tax thus allow for a cut in the labour tax rate. For the Laffer curves to slope upwards, the public sector should not be too large, i.e. the initial tax rates (τ, t_L and t_R) should not be large, so that an erosion of the tax bases yields only relatively minor adverse effects for public revenues. With large initial tax rates, own and cross price elasticities for factor demand should be small in order to prevent a large erosion of tax bases. In particular, a high initial tax rate on labour is consistent with upward-sloping Laffer curves if the wage elasticity of labour demand (ϵ_{Lw}) is small, resources and labour are non-cooperative factors ($\epsilon_{Lq} < 0$), or the profit tax rate is small.

3.2 Environmental quality

Environmental damages rise with resource use. The relative change in resource use may be found from substituting (4) into (1′) while using $\omega_L \epsilon_{Lq} = \omega_R \epsilon_{Rw}$ and $\tilde{H} = 0$:

$$\tilde{R} = -\,[(1-\tau)(\epsilon_{Rq} - \epsilon_{Lq}) - \theta_L \epsilon_D]\; \omega_L \tilde{t}_R/\Delta^* \qquad (5)$$

where convavity of the production function ensures that $\epsilon_D \equiv \epsilon_{Lw}\epsilon_{Rq} - \epsilon_{Rw}\epsilon_{Lq} > 0$. We assume that the term in square brackets is positive. This is the case if the initial labour and profit tax rates

are not too large and, compared to resources, labour is not a much better substitute for the fixed factor.[2]

3.3 Employment

To obtain the effects of environmental tax reform on employment, we substitute (4) into the expression for labour demand given by (1′), use $\omega_L\epsilon_{Lq}=\omega_R\epsilon_{Rw}$ and obtain:

$$\hat{L} = [(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw}) - \theta_R\epsilon_D]\,\omega_R\tilde{t}_R/\Delta^*. \qquad (6)$$

Hence, employment expands if the initial tax on resources is zero (i.e. $\theta_R=0$) and profits are not fully taxed away ($\tau<1$).[3] Below we consider separately the three production functions discussed in section 2 by substituting the results for the various elasticities from Table 1 into (6).

(i) Resources separable: $\hat{L}=(1-\tau-\theta_R\sigma_R/\omega_H)\sigma_{LH}\omega_R\tilde{t}_R/\Delta^*$

If substitution between resources and value added Q is easy (i.e. σ_R large), the profit tax rate and the initial resource tax rate are large, and the production share of the fixed factor (ω_H) is small, employment falls. However, employment rises if the burden of environmental tax reform is mostly borne by the fixed factor. This is the case if substitution between resources and value added is difficult, profit and resource tax rates are small, and the fixed factor accounts for a large production share.

(ii) Labour separable: $\hat{L}=\{(1-\tau)\sigma_L-[(1-\tau)\omega_L+\theta_R\sigma_L(1-\omega_L)/\omega_H]\sigma_{RH}\}\omega_R\tilde{t}_R/(1-\omega_L)\Delta^*$

An employment dividend is more likely to occur if substitution between resources and the fixed factor is difficult (i.e. σ_{RH} small), the initial tax rates on resources and profit income are small, and the production share of the fixed factor is large. In that case, environmental policy is cheap (because of the small initial tax rate on resources) while the costs can be absorbed by the

[2] Table 1 provides expressions for the term $\epsilon_{Rq}-\epsilon_{Lq}$ for each of the three separable production functions. It indicates that this term is generally positive as the own price effect dominates the cross price effect. Only if labour is a much better substitute for the fixed factor than resources, may $\epsilon_{Rq}-\epsilon_{Lq}$ be negative. In this latter case, the labour tax is a much better instrument for environmental protection than the resource tax. We assume that this is not the case, so that $\epsilon_{Rq}-\epsilon_{Lq}>0$. This condition holds always for cases (ii) and (iii) and for case (i) if σ_R exceeds $\omega_R\sigma_{LH}$ - see Table 1.

[3] The term $\epsilon_{Lw}-\epsilon_{Rw}$ is always non-negative for cases (i) and (iii) described in section 2- see Table 1. However, this term may be negative for case (ii), i.e. if labour is separable from the other production factors. In particular, it is negative if, compared to labour, resources is a much better substitute for the fixed factor (i.e. σ_{RH} large relative to σ_L) - see Table 1. We rule out this possibility and thus assume $\epsilon_{Lw}-\epsilon_{Rw}>0$.

fixed factor (because of a large production share ω_H, a small elasticity σ_{RH}, and a small profit tax rate τ). Also, easy substitution between labour and the composite of resources and the fixed factor (i.e. σ_L large) makes a rise in employment more likely.

(iii) Fixed factor separable: $\hat{L}=(1-\tau-\theta_R\sigma_H/\omega_H)\sigma_{LR}\omega_R\tilde{t}_R/\Delta^*$

Employment rises if the initial profit tax rate and the initial tax rate on resource use are small, substitution between the fixed factor and the labour-resource composite is difficult (i.e. σ_H small), and the production share of the fixed factor is large. In that case, the increase in employment is particularly large if substitution between labour and resources is easy (i.e. σ_{LR} large).

The three cases examined above allow us to draw a number of conclusions about the circumstances under which an employment double dividend is likely. A necessary condition for employment to rise is that the after-tax income from the fixed factor can bear a large share of the tax burden.[4] This requires a small rate of profit taxation and a large production share of the fixed factor, ω_H. Indeed, if all profits are taxed away, an employment dividend never occurs.[5]

The tax rate on resource use should also be small for employment to rise.[6] The reason is that environmental protection is expensive if the initial tax rate on resource use is large. In particular, a large initial tax rate implies that the resource tax is a less effective instrument for raising public revenues because the erosion of the base of the resource tax causes a substantial decline in public revenues if the initial resource tax rate is large. Since the associated Laffer curve for the resource tax is thus flat, a rise in the tax rate on resource use allows only a small decline in the tax rate on labour.[7]

The production structure is another important determinant of the likelihood that an employment dividend occurs. In particular, for employment to rise, resources and the fixed

[4] Bovenberg and van der Ploeg (1993b) assume that all factors are mobile and that the labour market clears. Indeed, they find that employment never expands.

[5] A 100 per cent profit tax is, in fact, optimal, because the fixed fixed factor is in inelastic supply. Hence, an employment dividend can occur only if monitoring problems preclude a 100 per cent profit tax (see Atkinson and Stiglitz, 1980, pp. 467-468). In that case, a resource tax acts as an indirect tax on the fixed factor.

[6] If resource use is not taxed initially, employment rises (see equation (6), where we have ruled out $\epsilon_{Lw}-\epsilon_{Rw}\leq 0$, see footnote 3).

[7] In a model with a clearing labour market, Bovenberg and de Mooij (1992) also find that an environmental tax reform raises employment only if the initial tax rate on resource use is small and if part of the tax burden can be shifted towards the fixed (non-labour) factor of production.

factor must be poor substitutes. With poor substitution, the fixed factor bears a large part of the additional tax burden on resource use. In contrast to the fixed factor, labour should be a good substitute for resources in order for an employment dividend to occur. Intuitively, a large elasticity of substitution between resources and labour causes substantial substitution away from resources and towards labour when resources become more expensive relative to labour. Indeed, if labour is a better substitute for resources than the fixed factor, the substitution effect of the tax reform dominates the (negative) output effect so that the demand for labour expands.

3.4 Profit income

The relative change in after-tax profits, $(1-\tau)\Pi=(1-\tau)p_H H$, is found by using the factor price frontier (2′) and setting $\hat{w}=\tilde{q}=0$:

$$(1-\tau)\,\hat{\Pi} = -(1-\tau)\,(\omega_L\,\tilde{t}_L + \omega_R\,\tilde{t}_R) \qquad (7)$$

where $\hat{\Pi}\equiv d\Pi/Y$. The negative of expression (7) can be interpreted as a measure for the overall tax burden. Substituting the change in the labour tax rate (4) into (7), we obtain

$$(1-\tau)\,\hat{\Pi} = (1-\tau)\omega_R\omega_L\,[\theta_L\,(\epsilon_{Lw}-\epsilon_{Rw}) - \theta_R\,(\epsilon_{Rq}-\epsilon_{Lq})]\,\tilde{t}_R/\Delta^*. \qquad (7')$$

If the initial tax rates on labour and resources are zero, an environmental tax reform does not affect profit income. As we assume that the own price elasticities exceed the cross price elasticities (i.e. $\epsilon_{Lw}>\epsilon_{Rw}$, see footnote 3), an environmental tax reform raises profit income if initially only the tax on labour is positive. Conversely, if the economy starts off with a high dirt tax (θ_R large) and a low tax rate on labour, an environmental tax reform depresses profit income (as $\epsilon_{Rq}>\epsilon_{Lq}$, see footnote 2). Intuitively, the tax structure that maximises profit income and thus minimises the burden of taxation on profit income involves positive tax rates on both labour and resource use. Expression (7′) reveals that the profit-maximising tax structure is given by:

$$\theta_L/\theta_R = (\epsilon_{Rq}-\epsilon_{Lq})/(\epsilon_{Lw}-\epsilon_{Rw}). \qquad (7'')$$

Hence, the relative tax burden on labour varies inversely with the elasticity of labour demand ϵ_{Lw} and positively with the own price elasticity of resource demand ϵ_{Rq}. In accordance with the familiar Ramsey rules, the government should thus levy the heaviest taxes on relatively inelastic

tax bases. Table 1 indicates that, if the fixed factor is separable from the other production factors (i.e. case (iii)), the profit-maximising tax rates on labour and resources are equal (i.e. $\theta_L=\theta_R$).

3.5 Notional labour supply and involuntary unemployment

Households derive utility M from private consumption C and leisure N-L, where N denotes total working hours available, i.e. $M=M(C,N-L)$. Private consumption is simply given by the sum of wage income and after-tax profit income $C=wL+(1-\tau)\Pi$. With a rigid consumer wage (i.e. $\hat{w}=0$), labour demand determines effective labour supply. Notional labour supply L^s exceeds effective labour supply L and corresponds to the number of hours households would like to work at the going consumer wage w. Notional labour supply follows from setting the marginal rate of substitution between leisure $V\equiv N-L$ and consumption equal to the real wage, i.e. $M_{N-L}/M_C=w$ with the corresponding level of notional private consumption given by $C^s=wL^s+(1-\tau)\Pi$. Loglinearisation of the condition for the marginal rate of substitution yields $\hat{C}^s+(L/V)\hat{L}^s=\sigma\hat{w}$,[8] where σ stands for the elasticity of substitution between leisure and consumption in private utility. The loglinearised budget restriction for households amounts to $\omega_C\hat{C}=\omega_L(1-\theta_L)(\hat{w}+\hat{L}^s)+(1-\tau)\hat{\Pi}$, where $\omega_C\equiv C/Y$. Setting $\hat{w}=0$ and solving for the relative change in notional labour supply, we obtain:

$$\hat{L}^s \equiv dL^s/L = -(1-\tau)\hat{\Pi}/[\omega_L(1-\theta_L)+\omega_C(L/V)]. \qquad (8)$$

The positive income effect associated with a rise in after-tax profit income raises the demand for leisure, thereby reducing notional labour supply.

The level of involuntary unemployment amounts to the difference between notional labour supply and employment, i.e. $U\equiv L^s-L$, so that the the level of voluntary unemployment corresponds to $N-L^s=V-U$. The relative change in the level of involuntary unemployment is defined as $\hat{U}\equiv dU/L=\hat{L}^s-\hat{L}$. Hence, an environmental tax reform reduces involuntary unemployment if both employment and profit income expand. This is the case if initially there is no resource tax and not all profits are taxed away - see expressions (6) and (7′). Hence, the introduction of a small tax on resources generally boosts both employment and profit income, thereby cutting the levels of both notional labour supply and involuntary unemployment.

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[8] We assume that environmental quality enters utility in a separable fashion. Hence, changes in the quality of the environment do not affect the marginal rate of substitution between leisure and consumption.

3.6 Output

Substituting employment (6) and resource use (5) into the production function $\hat{Y} = \omega_L \hat{L} + \omega_R \hat{R}$, we obtain the relative change in output:

$$\hat{Y} = \{(1-\tau)[(\epsilon_{Lw}-\epsilon_{Rw})-(\epsilon_{Rq}-\epsilon_{Lq})] + (\theta_L-\theta_R)\,\epsilon_D\}\omega_R\omega_L\,\tilde{t}_R/\Delta^*. \qquad (9)$$

If the fixed factor is separable in production (i.e. case (iii)), $\hat{Y} = (\theta_L-\theta_R)\sigma_{LR}\sigma_H\omega_R\omega_L\tilde{t}_R/\omega_H\Delta^*$. Hence, an environmental tax reform boosts output if the initial tax rate on labour exceeds that on resource use. The increase in output is substantial if substitution between labour and resources and between the fixed factor and the labour-resource composite is easy, and the production share of the fixed factor ω_H is small. If in case (iii) the initial labour and resource tax rates are set at their profit-maximising levels (see (7″)), an environmental tax reform leaves output unaffected.

If resources are separable in production (i.e. case (i)), expression (9) features an additional term as $(\epsilon_{Lw}-\epsilon_{Rw})-(\epsilon_{Rq}-\epsilon_{Lq}) = (\sigma_{LH}-\sigma_R)/(1-\omega_R)$ - see Table 1. Hence, as long as not all profit income is taxed away, an environmental tax reform boosts output if substitution between labour and the fixed factor is relatively easy compared to substitution between resources and value added (i.e. $\sigma_{LH} > \sigma_R$). However, if labour is separable in production (i.e. case (ii)), the tax reform boosts output if substitution between labour and the composite of resources and the fixed factor is relatively easy compared to substitution between resources and the fixed factor (i.e. $\sigma_L > \sigma_{RH}$). Production thus expands, if compared to resources (the factor on which the tax rate is raised), labour (the factor on which the tax rate is cut) is a better substitute for the fixed factor.

3.7 Private consumption

To obtain the effects on private consumption, we loglinearise the budget constraint facing households:

$$\omega_C\,\hat{C} = \omega_L(1-\theta_L)\,\hat{L} + (1-\tau)\,\hat{\Pi}. \qquad (10)$$

Environmental tax reform thus boosts private consumption if both employment and profit income increase. Substituting employment (6) and profit income (7′) into (10), we obtain:

$$\omega_C\,\hat{C} = \{(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw}) - \theta_R\,[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) + \epsilon_D(1-\theta_L)]\}\omega_L\omega_R\,\tilde{t}_R/\Delta^* \qquad (10')$$

If we start off from a situation in which the tax rate on resource use is relatively small, environmental tax reform raises both employment and profit income and thus boosts also private consumption. However, if all profits are taxed away (i.e. $\tau = 1$) and the initial resource tax is zero (i.e. $\theta_R = 0$), none of these variables are affected by the introduction of a dirt tax.

If the fixed factor is separable in production (i.e. case (iii)), the term in curly brackets in expression (10′) becomes $[(1-\tau)(1-\theta_R)-(1-\theta_L)\theta_R\sigma_H/\omega_H]\sigma_{LR}$ - see Table 1. Hence, if the profit tax rate and the resource tax rate are large, the labour tax rate is small, substitution between the fixed factor and other factors is easy, and the production share of the fixed factor is small, an environmental tax reform is likely to hurt private consumption.

4 Welfare effects

4.1 Private utility: Pink and blue welfare

Labour supply is rationed due to a rigid consumer wage, which exceeds the reservation wage. The gap between the actual consumer wage and the reservation wage can be modelled as a virtual tax on labour, i.e. $s \equiv (w-w^*)/w_P\eta$ where η stands for the marginal cost of public funds and $w^* \equiv M_{N\cdot L}/M_C$ denotes the reservation wage (cf. Neary and Roberts, 1980; Bovenberg and van der Ploeg, 1993a). The reservation wage corresponds to the wage at which households would be willing to work. The virtual tax on labour, s, increases if the gap between the market wage and the reservation wage expands and thus provides a measure of the distortion in the labour market due to wage rigidities. The change in private utility M(C,V) can be expressed as a fraction of the national income as follows:

$$dM/M_C Y = [(w-w^*)L/Y]\hat{L} + (1-\tau)\hat{\Pi} = s\eta\omega_L\hat{L} + (1-\tau)\hat{\Pi}. \qquad (11)$$

Expression (11) indicates that a boost to employment yields a first-order welfare gain, which is proportional to the gap between the actual wage and the reservation wage as measured by the virtual labour tax. Defining the expansion of employment as the pink dividend and an increase in profits as the blue divided, we note from (11) that the impact on private utility amounts to the weighted sum of the pink and blue dividends. Hence, if there is both a pink and a blue dividend, private consumption and private utility rise while the level of involuntary unemployment falls.

Substituting after-tax profits (7) and the government budget constraint (3′) into (11), we can write the effect on private welfare in an alternative way:

$$dM/M_C Y = \omega_L [\theta_L + s\eta] \hat{L} + \omega_R \theta_R \hat{R}. \qquad (11')$$

Accordingly, private welfare is affected by both tax distortions (i.e. the terms with the tax rates θ_R and θ_L) and the non-tax distortion due to rationing on the labour market (i.e. the term with the virtual labour tax rate, s). Indeed, the term in square brackets at the right-hand side of (11′), which measures the gap between the social benefits (i.e. the marginal product of labour) and social costs (i.e. the reservation wage), amounts to the sum of tax and non-tax distortions. Substituting employment (6) and profit income (7′) into (11), we find:

$$dM/M_C Y = \{(1-\tau)(s\eta+\theta_L)(\epsilon_{Lw}-\epsilon_{Rw})-\theta_R[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq})-s\eta\epsilon_D]\}\omega_R\omega_L\tilde{t}_R/\Delta^*. \qquad (11'')$$

Introduction of a small dirt tax (i.e. initially $\theta_R=0$) boosts both employment and profit income, thereby raising private utility. The increase in private utility is particularly large if the initial tax rate on labour is high, the profit tax rate is small, public funds are scarce, the virtual tax on labour is high (i.e. the level of involuntary unemployment is high), and substitution between labour and resources is easy (i.e. $\epsilon_{Lw}-\epsilon_{Rw}$ is large, see Table 1).

4.2 Green welfare

Overall welfare is affected not only by private welfare but also by environmental damages. If environmental damages are represented by D(R), $D'>0$, the improvement in environmental quality (expressed in dollars) of an environmental tax reform is given by $-dD/M_C$, where M_C denotes the marginal utility of private consumption. The virtual subsidy on resource use on account of no price being charged for the associated environmental damages, i.e. p, equals the marginal environmental damages (expressed in dollars) divided by the marginal cost of public funds η, i.e. $p \equiv D'/M_C q_P \eta$ (cf. Bovenberg and van der Ploeg, 1993a). The effect on environmental welfare, which we call the green dividend, can thus be expressed as a fraction of the national income as follows:

$$-dD/M_C Y = -p\eta\omega_R \hat{R} = p\eta [(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) - \theta_L\epsilon_D]\omega_R\omega_L \tilde{t}_R/\Delta^* \qquad (12)$$

where (5) has been used to substitute the change in resource demand.

4.3 Overall welfare

Using (11′) and (12), we find the change in overall welfare:

$$dU/M_C Y = (dM-dD)/M_C Y = \omega_L (\theta_L+s\eta) \hat{L} + \omega_R (\theta_R-p\eta) \hat{R}. \qquad (13)$$

The terms in round parentheses at (last) right-hand side of (13) represent the gaps between the social benefits and costs of employment and resource use, respectively. These gaps can be interpreted as the distortions in the labour and resource markets. They amount to the sum of tax and non-tax distortions. Without initial taxes (i.e. $\theta_L=\theta_R=0$), an expansion of employment enhances welfare due to rationing on the labour market. More resource use, in contrast, hurts welfare as producers fail to internalise the environmental damages associated with resource use. Hence, whereas taxes on labour exacerbate the distortions due to rationing, taxes on resources alleviate the distortions due to pollution externalities.

Alternatively, by substituting (11) and (12) into (13), the overall welfare effect can be expressed as the sum of the pink, green and blue dividends:

$$dU/M_C Y = \eta s\omega_L \hat{L} - \eta p\omega_R \hat{R} + (1-\tau) \hat{\Pi}. \qquad (13')$$

If we start from a situation with only a positive tax on labour (i.e. $\theta_L>0$, $\theta_R=0$), an environmental tax reform typically yields a triple dividend as it boosts employment (see (6)), profit income (see (7′)), and environmental quality (see (5)).[9] Intuitively, minimising the burden of taxation on income from the fixed factor requires that the government spreads the tax burden over both labour and resources (see (7″)). The social objectives of stimulating employment and reducing pollution strengthen the case for a higher tax on resources and a lower tax on labour.

4.4 Optimal tax rates

We find the change in total welfare in terms of the change in the tax rate on the use of resources by substituting employment (5), resource use (6) and after-tax profits (7′) into (13′):

$$dU/M_C Y = \{s[(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw})(\eta-1)-\eta(\theta_R-p)\epsilon_D] + p[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq})(\eta-1)-\eta(\theta_L+s)\epsilon_D]$$

$$+ (1-\tau)[(\theta_L+s)(\epsilon_{Lw}-\epsilon_{Rw})-(\theta_R-p)(\epsilon_{Rq}-\epsilon_{Lq})]\}\ \omega_L\omega_R\tilde{t}_R/\Delta^*. \qquad (13'')$$

At an optimum the change in overall welfare must be zero. This yields the optimal tax rates on the use of labour and resources (cf. Bovenberg and van der Ploeg, 1993a):

[9] We assume that $\epsilon_{Rq}-\epsilon_{Lq}>0$ and $\epsilon_{Lw}-\epsilon_{Rw}>0$, see footnotes 2 and 3.

$$\theta_R - p = (1-\eta^{-1})\,(1-\tau)\,(\epsilon_{Lw}-\epsilon_{Rw})/\epsilon_D \qquad (14)$$

$$\theta_L + s = (1-\eta^{-1})\,(1-\tau)\,(\epsilon_{Rq}-\epsilon_{Lq})/\epsilon_D. \qquad (15)$$

The optimal resource tax rate rises with the environmental externalities (as measured by the virtual pollution subsidy, see expression (14)) while the optimal labour tax rate declines with the virtual labour tax rate caused by a rigid consumer wage (see expression (15)). Hence, the resource tax acts to offset the implicit subsidy on pollution due to environmental externalities (p) while the labour tax offsets the virtual tax due to rationing of labour supply. The optimal 'distortionary' components of the resource and labour tax rates are given by, respectively, θ_R-p and θ_L+s. These distortionary components measure the wedges between the social benefits and social costs of the two inputs. They thus amount to the sum of the explicit tax rates (i.e. θ_R and θ_L) and the implicit taxes due to non-tax distortions (i.e. -p and s). Expressions (14) and (15) indicate that these components rise with the scarcity of public revenues as measured by the marginal cost of public funds (η). Furthermore, the relative magnitude of distortions in resource and labour demand depends on how sensitive factor demands are with respect to the tax wedges:

$$(\theta_L+s)/(\theta_R-p) = (\epsilon_{Rq}-\epsilon_{Lq})/(\epsilon_{Lw}-\epsilon_{Rw}). \qquad (16)$$

Without cross price effects in factor demands, the distortionary component of the labour tax exceeds that of the resource tax if labour demand is inelastic with respect to the producer wage while resource demand is relatively elastic with respect to the producer price of resources. Hence, in accordance with the familiar Ramsey rule, the government should levy the highest tax on the factor with relatively inelastic demand.

5 Starting from an optimal tax system

This section discusses the effects of an environmental tax reform starting from an optimal tax system based on a virtual subsidy for pollution (p) and a virtual tax on labour (s). This experiment should be interpreted as the government adjusting the optimal tax system in response to a shock in preferences towards more environmental concern.[10] Using expressions (14) and (15) to eliminate θ_R and θ_L from the expressions contained in Table 2, we find the results contained in Table 3. The remainder of this section interprets these results.

[10] Alternatively, this shock can be interpreted as an increase in the perceived adverse impact on the environment of resource use.

5.1 The labour tax rate

The environmental tax reform allows for a cut in the tax rate on labour if the Laffer curve for the resource tax slopes upwards. A sufficient condition for an upward-sloping Laffer curve is that the profit tax rate and initial environmental concern (as indicated by p) are small. By reducing profits and resource use, a higher resource tax rate erodes the bases of both the profit tax and the resource tax. The adverse effect on public revenues of an eroding tax base (the tax base effect) may offset the revenue-enhancing effect of a higher tax rate (the tax rate effect) only if the profit tax rate is large or, due to a high social priority for the environment, the resource tax rate is high. Even with a high initial resource tax rate, the resource tax yields positive net revenues if the own price elasticity of resource demand (ϵ_{Rq}) is small.

5.2 Employment

Without initial environmental concern (i.e. p=0), employment rises in response to a small increase in the resource tax. If the initial situation features environmental concern, employment declines if the production share of the fixed factor is small (implying that the term ϵ_D is large, see Table 1), the profit tax rate is large, substitution between labour and resources is difficult (implying that the term ϵ_{Lw}-ϵ_{Rw} is large, see Table 1), and substitution between the fixed factor and resources is easy (implying that the term ϵ_D is large, see Table 1). The roles of the initial after-tax income accruing to the fixed factor, which is affected by the profit tax rate and the pre-tax income share ω_H, and the substitution elasticities in production were explained in sub-section 3.3.

The relevance of the initial degree of environmental concern can be explained as follows. If society attaches a high priority to environmental quality in the initial equilibrium, a further tightening of environmental policy is expensive and yields little room to reduce the tax rate on labour. In particular, at a high initial resource tax rate, an increase in that tax is not very effective in raising more public revenues due to the erosion of the tax base.

Our results are based on loglinearisation and thus hold only for small changes. In this respect, the importance of the initial degree of environmental concern suggest that small increases in resource taxes from their optimal values in an equilibrium without environmental concern raise employment. Large increases in resource taxes, in contrast, may well harm employment. A fall in employment is especially likely if fixed factors are either unimportant or are good substitutes for resources so that output declines substantially. These conditions are more likely to be met in the long run than in the short run. Hence, employment may well rise in the short run but fall in the long run. This observation is especially relevant for small open

economies in which most factors of production are internationally mobile in the long run.

Using (14) to eliminate ϵ_{Lw}-ϵ_{Rw} from the entry for employment in Table 3, we arrive at the following alternative expression for the relative change in employment:

$$\tilde{L} = \{(\theta_R - D'/M_C q_P)\, \omega_R \epsilon_D / [\Delta^*(1-\eta^{-1})]\}\, \tilde{\tau}_R. \qquad (17)$$

Given that we start from an optimal tax system, employment expands if and only if the resource tax exceeds the marginal environmental damages (expressed into dollars).

5.3 Resource use

The use of resources and thus environmental damages decline (given that we assume ϵ_{Rq}-ϵ_{Lq}>0). Environmental quality improves substantially if the fixed factor accounts for a small income share and is a good substitute for resources so that the term ϵ_D is large. Under these circumstances, employment is likely to decline if the initial equilibrium features initial environmental concern (see sub-section 5.2). Hence, the role of the fixed factor causes a trade-off between the green and pink dividends. Whereas a small fixed factor that is a good substitute for resources helps the environment, it hurts employment.

5.4 After-tax profits

The tax reform does not affect profits if initial non-tax distortions are zero. This can be explained as follows. Without any social (non-tax) objectives, the tax system can focus entirely on raising public revenues. Hence, the optimal tax system minimises the overall tax burden for achieving an exogenous revenue target. Exogenous consumer wages and a fixed global market price for resources imply infinitely elastic supplies of labour and resources, so that the fixed factor bears the entire tax burden. Accordingly, the optimal tax system aims at maximising after-tax profits (and thus satisfies expression (7″)). This implies that a marginal shift away from labour to resource taxation does not affect after-tax profits.

With initial non-tax distortions, profits decline on account of a change in the tax mix away from labour and toward resource taxation. The reason is that in the presence of tax distortions, the tax system focuses not only on raising public revenues at minimum costs to after-tax profits but also on other social objectives (i.e. environmental protection and employment creation). In particular, compared to the labour tax, the resource tax plays an excessive role in the initial tax system from the point of view of maximising after-tax profits

(compare expression (7″) with (14) and (15));[11] resource taxes are relatively high in order to improve environmental quality while labour taxes are relatively low in order to enhance employment. The environmental tax reform further strengthens the role of resource taxation in the overall tax mix, thereby hurting profits. Intuitively, the tax system focuses even less on raising public revenues at the least cost to the fixed factor and rather more on the objective of environmental protection.

5.5 Output

Without initial tax distortions, the sign of the effect on output depends on whether resources or labour is the best substitute for the fixed factor. In particular, output expands if labour is the best substitute for the fixed factor, which implies that the term ϵ_{Lw}-ϵ_{Rw} exceeds the term ϵ_{Rq}-ϵ_{Lq}. In that case, the tax rate on the better substitute for the fixed factor (i.e. labour) is reduced. This implies that output expands. Without tax distortions, output is unaffected by the environmental tax reform if the fixed factor is separable in production (i.e. case (iii) in Table 1).

If the initial tax system has non-revenue objectives (i.e. s or p are positive), output is likely to fall. The intuition behind this result is similar to that discussed in sub-section 5.4. With non-tax distortions, the optimal tax system balances the objective of maximising output with the other social objectives of environmental protection and high levels of employment.

5.6 Welfare effects

Starting from an optimal tax system, the tax reform can not raise all three components of social utility. Hence, a triple dividend implying a rise in pink, blue and green welfare is excluded. Indeed, with initial non-tax distortions, blue welfare (i.e. after-tax profits) always declines. Whereas green welfare increases, the impact on pink welfare is ambiguous. Accordingly, society pays for a cleaner environment in the form of a lower level of after-tax profits. Pink welfare has to pay a price as well if either after-tax profits are unimportant or if environmental policy is expensive (because of a high initial level of environmental concern) (see sub-section 5.2). Without initial environmental concern, however, a small increase in the resource tax yields a double dividend as both green and pink welfare increase. The excess burden as measured by the impact of raising a given amount of public revenues on after-tax profits increases. However, the tax system yields more excess benefits in terms of the social objectives

[11] We assume that both ϵ_{Lw}-ϵ_{Rw} and ϵ_{Rq}-ϵ_{Lq} are positive (see footnotes 2 and 3). Hence, employment is too high and resource use is too low from the point of view of maximising the after-tax return to the fixed factor.

of employment creation and environmental protection.

6 Using dirt taxes to finance public spending: Green-red reform

So far, we assumed that any additional public revenue generated by a higher dirt tax is handed back by reducing the tax rate on labour. Many left-of-centre politicians argue, however, that additional revenue should be used to fund public spending while leaving the tax rate on labour unchanged. This may be referred to as a green-red reform of the public sector. The consequences of such a reform are presented in Table 4. Under such a reform there is always a green dividend, i.e. $\hat{R}=-\epsilon_{Rq}\tilde{t}_R<0$. Employment falls if labour and resources are cooperative factors of production, since $\hat{L}=-\epsilon_{Lq}\tilde{t}_R<0$ if $\epsilon_{Lq}>0$. In that case, production falls as well. This is always the case if resources or labour are separable in production (see cases (i) and (ii) in Table 1). However, if the fixed factor is separable in production, employment rises if substitution between labour and resources is much easier than substitution between the fixed factor and the labour-resource composite and if the production share of the fixed factor is large. Profit income always falls under a green-red reform, i.e. $(1-\tau)\hat{\Pi}=-(1-\tau)\omega_R\tilde{t}_R<0$. Hence, if labour and resources are cooperative factors, employment, private consumption and private utility fall. The decline in profit income induces a higher level of notional labour supply (see equation (8)). Hence, the level of involuntary unemployment rises if resources and labour are cooperative factors. Compared with an environmental tax reform, a green-red reform imposes a heavier burden on the private sector in order to make room for a larger public sector.

7 Conclusion

This paper has shown that, starting from a sub-optimal tax system, a shift in the tax burden away form labour towards resources may yield a triple dividend in that not only environmental quality improves but also employment expands and after-tax profits rise. In particular, this case occurs if the initial resource tax is zero. In that case, notional labour supply and the level of involuntary unemployment fall while private consumption, private utility and thus overall welfare increase. The point is that, even in the absence of non-tax distortions, it is optimal to spread the tax burden over labour and resources. With environmental externalities and labour market distortions, the case for a resource tax becomes even stronger in order to internalise pollution externalities and reduce the tax burden on labour, thereby mitigating the gap between the marginal productivity of labour and the reservation wage due to rigid consumer wages.

If the initial equilibrium features an optimal tax system, however, a triple dividend is

excluded. Only if the initial equilibrium is characterised by the absence of environmental concern and the equality between consumer and reservation wages, which implies no non-tax distortions, does an environmental tax reform leave after-tax profits unaffected. In the presence of non-tax distortions, however, profits always decline. If initially there are only labour market distortions, a shift away from labour taxation still yields a double dividend in the sense that both employment and environmental quality increase. If the initial equilibrium exhibits not only labour market distortions but also environmental externalities, employment may decline, especially if the fixed factor is a relatively unimportant production factor or is a good substitute for resources. Fixed factors are more important in the short run than in the long run. Accordingly, an environmental tax reform is more likely to yield an employment dividend in the short run than in the long run. In a small open economy fixed production factors generally do not play an important role – even in the short run. Hence, a double dividend is unlikely to occur if the initial tax system is optimal.

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Table 1: Separability in production and factor demand elasticities

	Case (i) $Y=F(Q(L,H),R)$	Case (ii) $Y=F(Q(R,H),L)$	Case (iii) $Y=F(Q(L,R),H)$
ϵ_{Lw}	$\sigma_{LH}(1-\omega_R)/\omega_H$	$(\sigma_L+\sigma_{RH}\omega_L\omega_R/\omega_H)/(1-\omega_L)$	$(\sigma_{LR}\omega_R+\sigma_H\omega_L/\omega_H)/(1-\omega_H)$
ϵ_{Lq}	$\sigma_{LH}\omega_R/\omega_H$	$\sigma_{RH}\omega_R/\omega_H$	$[(\sigma_H/\omega_H)-\sigma_{LR}]\omega_R/(1-\omega_H)$
ϵ_{Rq}	$(\sigma_R+\sigma_{LH}\omega_L\omega_R/\omega_H)/(1-\omega_R)$	$\sigma_{RH}(1-\omega_L)/\omega_H$	$(\sigma_{LR}\omega_L+\sigma_H\omega_R/\omega_H)/(1-\omega_H)$
ϵ_{Rw}	$\sigma_{LH}\omega_L/\omega_H$	$\sigma_{RH}\omega_L/\omega_H$	$[(\sigma_H/\omega_H)-\sigma_{LR}]\omega_L/(1-\omega_H)$
$\epsilon_{Lw}-\epsilon_{Rw}$	σ_{LH}	$(\sigma_L-\omega_L\sigma_{RH})/(1-\omega_L)$	σ_{LR}
$\epsilon_{Rq}-\epsilon_{Lq}$	$(\sigma_R-\omega_R\sigma_{LH})/(1-\omega_R)$	σ_{RH}	σ_{LR}
ϵ_D	$\sigma_{LH}\sigma_R/\omega_H$	$\sigma_{RH}\sigma_L/\omega_H$	$\sigma_{LR}\sigma_H/\omega_H$

Note: $\epsilon_D \equiv \epsilon_{Lw}\epsilon_{Rq}-\epsilon_{Rw}\epsilon_{Lq} > 0$

Table 2: Consequences of environmental tax reform for unemployment and welfare

	Increase in the tax rate on resources $\tilde{t}_R > 0$
Tax rate on labour $\tilde{t}_L$	$-[(1-\tau)\omega_R - \theta_L\omega_L\epsilon_{Lq} - \theta_R\omega_R\epsilon_{Rq}] < 0$
Employment $\tilde{L}$	$[(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw}) - \theta_R\epsilon_D]\ \omega_R$
Resource use $\tilde{R}$	$-[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) - \theta_L\epsilon_D]\ \omega_L$
Profit income $(1-\tau)\tilde{\pi}$	$(1-\tau)\omega_R\omega_L\ [\theta_L\ (\epsilon_{Lw}-\epsilon_{Rw}) - \theta_R\ (\epsilon_{Rq}-\epsilon_{Lq})]$
Private consumption $\omega_C\tilde{C}$	$\{(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw})-\theta_R\ [(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq})+\epsilon_D(1-\theta_L)]\}\omega_L\omega_R$
Output $\tilde{Y}$	$\{(1-\tau)[(\epsilon_{Lw}-\epsilon_{Rw})-(\epsilon_{Rq}-\epsilon_{Lq})] + (\theta_L-\theta_R)\ \epsilon_D\}\omega_R\omega_L$
Private utility dM/M_CY	$\{(1-\tau)(s\eta+\theta_L)(\epsilon_{Lw}-\epsilon_{Rw})$ $-\theta_R[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq})-s\eta\epsilon_D]\}\ \omega_R\omega_L$
Green welfare $-dD/M_CY$	$p\eta\ [(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) - \theta_L\epsilon_D]\ \omega_R\omega_L$

Note: The entries in the second column show the percentage effects of a one percentage rise in the tax rate on the use of resources divided by $\Delta^* \equiv (1-\tau)\omega_L-\theta_L\omega_L\epsilon_{Lw}-\theta_R\omega_R\epsilon_{Rw} > 0$, given that the additional public revenues are used to reduce the labour tax rate.

Table 3: Optimal responses to a higher priority for environmental protection

	Increase in the tax rate on resources $\tilde{t}_R > 0$
Tax rate on labour $\tilde{t}_L$	$-[(1-\tau) + s^*\epsilon_{Rw} - p^*\epsilon_{Rq}]\ \omega_R < 0$
Employment $\tilde{L}$	$[(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw}) - p^*\epsilon_D]\ \omega_R$
Resource use $\tilde{R}$	$-[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) + s^*\epsilon_D]\ \omega_L$
Private consumption $\omega_C\tilde{C}$	$\{(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw})(w^*/w_P)$ $- p^*\ [(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq})+\epsilon_D/(1+t_L)]\}\ \omega_L\omega_R$
Output $\tilde{Y}$	$-\{(1-\tau)[(\epsilon_{Rq}-\epsilon_{Lq})-(\epsilon_{Lw}-\epsilon_{Rw})]+(s^*+p^*)\epsilon_D\}\omega_R\omega_L$
Pink dividend $s^*\omega_L\tilde{L}$	$[(1-\tau)(\epsilon_{Lw}-\epsilon_{Rw}) - \epsilon_D p^*]\ s^*\ \omega_R\omega_L$
Blue dividend $(1-\tau)\tilde{\Pi}$	$-[(\epsilon_{Lw}-\epsilon_{Rw})s^* + (\epsilon_{Rq}-\epsilon_{Lq})p^*]\ (1-\tau)\ \omega_R\omega_L$
Green dividend $-p^*\omega_R\tilde{R}$	$[(1-\tau)(\epsilon_{Rq}-\epsilon_{Lq}) + \epsilon_D s^*]\ p^*\ \omega_R\omega_L$

Note: The entries in the second column show the percentage effects of a one percentage rise in the dirt tax divided by $\Delta^* \equiv \omega_L[1-\tau+s^*\epsilon_{Lw}-p^*\epsilon_{Lq}] > 0$. We define $p^* \equiv p\eta = D'/M_Cq_P$ and $s^* \equiv s\eta = (w-w^*)/w_P$, where p and s are evaluated at the initial optimum.

Table 4: Consequences of a green-red reform of the public sector

	Increase in the tax rate on resources $\tilde{t}_R > 0$
Tax rate on labour $\tilde{t}_L$	0
Employment $\tilde{L}$	$-\epsilon_{Lq}$
Resource use $\tilde{R}$	$-\epsilon_{Rq} < 0$
Profit income $(1-\tau)\tilde{\pi}$	$-(1-\tau)\omega_R \leq 0$
Private consumption $\omega_C\tilde{C}$	$-\omega_L(1-\theta_L)\epsilon_{Lq} - (1-\tau)\omega_R$
Public consumption $\omega_G\tilde{G}$	$(1-\tau)\omega_R - \theta_L\omega_L\epsilon_{Lq} - \theta_R\omega_R\epsilon_{Rq}$
Output $\tilde{Y}$	$-\omega_L\epsilon_{Lq} - \omega_R\epsilon_{Rq}$
Private utility dM/M_CY	$-s\eta\omega_L\epsilon_{Lq} - (1-\tau)\omega_R$
Green welfare $-dD/M_CY$	$p\eta\omega_R\epsilon_{Rq} \geq 0$

Note: The entries in the second column show the percentage effects of a one percentage rise in the tax rate on the use of resources, given that the additional public revenues are used to expand public consumption.

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