Environmental Quality and Social Insurance[f]

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Environmental Quality and Social Insurance

Abstract This paper examines the double dividend hypothesis under wage uncertainty. In the presence of two market failures we show that second-best requires a lower than the Pigouvian tax, and a higher than “first-best” labour income tax. Starting from a state in which the environmental tax is below second best, we consider increasing it and at the same time recycle the additional revenues to reduce labour income tax. This revenue recycling policy has three effects: the positive *Pigouvian effect*, the negative *tax interaction effect* and the *revenue recycling effect* which is positive under certainty. In the presence of uncertainty, we find that the revenue recycling effect is negative if labour income tax is below second best, due to the *social insurance effect*. Our results have significant policy implications. First, environmental policies that do not generate revenue could be equally efficient to those that generate revenue. Second, revenues generated by environmental policies should not be used to decrease labour income taxes. We argue that environmental recycling policies can violate the uncontroversial, in the case of certainty, weak form double dividend hypothesis.

I. Introduction

Environmental problems are increasingly becoming central issues of public policy at the national and, more recently, the international level. Although direct regulation is still the predominant form of environmental policy, there is a significant move toward policies that provide economic incentives. Economists have long been advocating the use of these policies on the basis of efficiency. More recently, it has been argued that the efficiency benefits of those policies that generate revenue, may extend beyond the environmental area, if revenues are used to decrease existing labour income taxes.

The benefit of revenue recycling derives from the assumption that labour income taxation is inefficient. However, it has been shown that in the presence of uncertainty over labour income, and assuming risk aversion, labour income taxation corrects for the missing insurance market in human capital. Our paper examines the welfare effects of revenue recycling environmental policies within the framework of uncertainty over labour income. We find that, contrary to common beliefs, the revenue recycling effect is negative. We also derive the second-best optimal mix of environmental and labour income taxes under uncertainty.

The interdependency of environmental taxes with other existing taxes was first examined by Sandmo (1975). However, it was not until recently that the environmental literature discussed the policy implications of these interdependencies and noted the possibility of using the revenues from environmental taxes to reduce labour income taxes, which under certainty are distortionary (see for example Oates (1993) and (1995), Pearce (1991), Repetto et al. (1992)). This has been termed the *revenue recycling effect*. More recently a direct interdependence was recognized. Increases in environmental taxes lead to higher prices and thus to a reduction in real wages which yield an additional welfare loss in the labour market (see for example, Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996), Parry (1995) and (1996) and the review of this literature in Goulder (1995)). This has been termed the *tax-interaction effect*. It has been shown that the latter tends to dominate the former effect (see for example Goulder (1996)). Thus, under certainty, the policy recomedation is to use the revenues of environmental tax to reduce labour income tax, in order to partially offset the tax interaction effect.

Our paper identifies a third effect in the presence of wage uncertainty. The reduction of labour income taxation increases uncertainty, and thus, yields an additional welfare loss in the labour market. This is termed the *social insurance effect*. The direction and strength of the social insurance effect depends on the existing level of taxes relative to their second-best optimum. In the presence of two market failures (missing insurance markets and environmental externality) we show that second-best optimum requires a lower than the Pigouvian tax, and a higher than "first-best" labour income tax. We demonstrate that if we start from a state of underinsurance, the social insurance effect reverses the sign of the revenue recycling effect. Thus, recycling of revenues exacerbates rather than alleviates the unavoidable negative tax interaction effect.

Our results have important policy implications. First, in terms of the choice of the appropriate policy instrument, environmental policies that do not generate revenues (such as grandfathered emission permits) *are equally* efficient to the revenue generating ones (such as environmental taxes and auctioned emission permits). Second, revenues generated by environmental policies *should not* be used to decrease labour income taxes. Therefore, alternative uses of potential revenues from environmental taxation, such as other types of distortionary taxation, should be explored. Within a completely different framework, Fullerton and Metcalfe (1996) suggest that particular non revenue raising environmental policies (such as subsidies to the clean good) may be equally efficient to revenue raising ones, even under certainty.

The remaining of the paper is organized as follows: section II describes the model; section III analyses the interaction between environmental and labour income tax under wage uncertainty; section IV examines the employment-leisure choice under uncertainty and section V determines second-best environmental and labour income taxes. The latter two sections provide the necessary background in order to determine the sign of the social insurance effect and thus, the sign of the welfare effect of revenue recycling policies. Section VI contains the discussion of the results and the concluding remarks.

II. The model

On the production side, we assume that labour is the only input in the production of the only two consumption goods *D* and *C*. Both production processes exhibit constant returns to scale and the markets for both goods are competitive. We normalize units such that the pre-tax prices of both goods are unity. Good C is assumed to be the environmentally clean good. The production of good D generates emissions that adversely affect the quality of the environment. Thus, environmental quality, $\Pi = \Pi(D)$, with $\Pi_D < 0$. We further assume that firms do not internalize any part of the externality in the absence of regulation, and that the marginal product of labour in both industries is independent of environmental quality.

We assume that households face uncertainty over their wages and the market fails to provide insurance.[1] The government's function is threefold: to provide a certain amount of a public good, $\bar{G}$; a certain level of environmental quality, Π; and insurance against wage uncertainty in the form of a lump-sum transfer, Ω. To serve these functions, the government generates revenue through a lump-sum income tax, T_0, a proportional tax on labour income, τ_L and a per unit tax, τ_D on D. The labour income insurance policy has two components; the spread of the wage distribution is reduced via τ_L, while the mean is preserved via Ω.[2] The government's budget constraint, expressed in per household terms, is

$$T_0 + \tau_L \bar{w}(T - l) + \tau_D D = \bar{G} + \Omega \ , \qquad \textbf{(1)}$$

where T-l is the household's labour supply, with l denoting leisure and T time endowment. Although for households w is stochastic, the government's budget is nonstochastic, since the government pools together idiosyncratic risks efficiently. $\bar{w}$ denotes the mean of the wage distribution.[3]

The representative household, faced with uncertainty over the pretax wage rate w holds a probability distribution over possible wages. It enjoys a given quality of environment, a given quantity of a public good, and receives a lump-sum transfer of money that depends on its ex post

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1 This is a very reasonable assumption. For discussions on moral hazard issues associated with insurance against wage uncertainty, see Arrow (1971), Varian (1980).

2 It should be noted that the present paper ignores distributional concerns. The lump-sum transfer, Ω is just part of the insurance policy and does not serve any distributional policy. Within our model, households have the same ex ante income. Thus, our results are based on efficiency rather than distributional considerations.

3 The central limit theorem guarantees certainty at the aggregate level.

wage rate. The households' budget constraint is

$$\left(1+\tau_D\right)D + C = \left(1-\tau_L\right)w(T-l) + \omega + \Omega - T_0 \ , \qquad \textbf{(2)}$$

where ω is the household's non-labour income. Assuming separability between environmental quality, public good, and consumption of *D*, *C* and *l*, households' utility function is $U(D,C,l) + V\left(\Pi,\bar{G}\right)$.[4] We make the usual assumptions of a twice differentiable, quasi-concave *U(·)*, exhibiting decreasing marginal utility of consumption.[5] We further assume that *V(·)* is increasing in Π and concave.

III. Interaction of income and environmental taxation under wage uncertainty

We assume that at some positive level of τ_L and τ_D, the government considers a marginal increase in environmental tax τ_D within a revenue-neutral policy. The environmental tax is a corrective tax, in the sense that it internalises an existing externality. The proportional labour income tax, in the absence of uncertainty, is a distortionary tax in the sense that it changes the shadow price of leisure. The effects of using corrective taxation revenues in reducing the distortionary tax within a revenue-neutral policy, is considered positive and has been termed the *revenue recycling effect*. However, corrective taxation is not equivalent to lump-sum taxation since it results in price increases, and thus, leads to distortions in the labour market through reductions in factor prices, a negative effect that is termed the *tax interaction effect*.[6] If the former effect outweighs the latter, environmental taxation generates a *double dividend*, i.e. an additional positive effect to the *Pigouvian effect*. However, recent work suggests that the opposite is more likely to be the case.[7]

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4 The assumption of separability simplifies our analysis without affecting our results qualitatively. Especially since environmental quality is more likely to be a complement rather than a substitute to leisure.

5 Decreasing marginal utility of consumption implies risk aversion

6 We use the terminology developed in Goulder et al. (1996).

7 See Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996), Goulder (1995) and (1996), Parry (1995) and (1996), and Goulder, Parry and Bertraw (1996).

Consider now the case that households do not know with certainty the return to their labour effort when they make their labour-leisure decisions. It has been shown that in addition to the distortionary effect associated with revenue generation, proportional labour income tax has the positive effect of lowering households' risks by pooling them across the economy.[8] Thus, changing the labour income tax under uncertainty has clearly an additional effect, hereafter called *social insurance effect.*

We determine the total welfare effect of a change in the environmental tax. That is, we want to account for the direct effect on the household's optimal choices as well as the indirect effect through the change in labour income tax implied by the revenue recycling policy. We first derive the total change in τ_L by totally differentiating government's budget constraint, equation (1). Since we consider a revenue neutral policy, i.e. $d(\bar{G} + \Omega) = 0$, we obtain

$$\frac{d\tau_L}{d\tau_D} = -\frac{D + \tau_D(\partial D/\partial\tau_D) - \tau_L\bar{w}(\partial l/\partial\tau_D)}{\bar{w}(T - l) - \tau_L\bar{w}(\partial l/\partial\tau_L) + \tau_D(\partial D/\partial\tau_L)} \ . \qquad \textbf{(3)}$$

The sign of the relative marginal tax revenue from environmental tax to labour income tax is positive and thus, $d\tau_L/d\tau_D < 0$.

Households are assumed to maximize

$$E\left[U(D,C,l)\right] + V(\Pi, \bar{G}) \ , \qquad \textbf{(4)}$$

with expectations based on the probability distribution of *w*. The first order conditions are

$$E[U_D] = (1 + \tau_D)E[U_C] , \quad \textit{and} \quad E[U_C(1 - \tau_L)w] = E[U_L] , \qquad \textbf{(5)}$$

where the subscripts *D*, *C* and *L* denote partial derivatives. Assuming that the budget constraint is binding, the first order conditions yield

$$D(\tau_D, \tau_L, w) \ , \quad C(\tau_D, \tau_L, w) \ , \quad l(\tau_D, \tau_L, w) \ . \qquad \textbf{(6)}$$

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8 Under uncertainty, increases in labour income taxation can have a positive effect on labour supply as will be discussed in the following section. See Eaton and Rosen (1980a) and (1980b), Varian (1980), Myles (1996).

We substitute the optimal choices from (6) into government's and household's budget constraints, equations (1) and (2) respectively, which we then combine to derive the individual's production possibility frontier[9]

$$C + D + \bar{G} = w(T - l) - \tau_L(w - \bar{w})(T - l) + \omega \ . \qquad \textbf{(7)}$$

Equation (7) restates the household's production constraint when the state provides social insurance. If the realization of household's wage rate is above the mean, i.e. $w > \bar{w}$, it pays labour income taxes while in the opposite case it receives a transfer payment.

Substituting the demands from (6) and the budget constraint from (7) into the household's utility function, yields the indirect utility function

$$u = E\Big[\, U\Big[D, w(T - l) - \tau_L(w - \bar{w})(T - l) - D - \bar{G} + \omega, l\Big]\Big] + V\big[\,\Pi(D), \bar{G}\big] \ . \qquad \textbf{(8)}$$

Differentiating the indirect utility function with respect to τ_D yields the total effect of a marginal increase in the environmental tax[10]

$$\frac{1}{E[U_C]}\frac{du}{d\tau_D} = (\mu d - \tau_D)\left(-\frac{\partial D}{\partial \tau_D}\right) + \Theta\left[D + \tau_D\frac{\partial D}{\partial \tau_D}\right] - (1 + \Theta)\,\tau_L\bar{w}\frac{\partial l}{\partial \tau_D} \ , \qquad \textbf{(9)}$$

where $\mu d = -V'\Pi_D / E[U_C]$ denotes marginal external damages, and Θ is the *marginal welfare change due to labour taxation per dollar of revenue raised*[11]

$$\Theta = -\frac{-\bar{w}\tau_L(\partial l/\partial\tau_L) + (\mu d - \tau_D)\,(-\partial D/\partial\tau_L) - \big[cov(U_C, w)(T - l)\big]/E[U_C]}{\bar{w}(T - l) - \tau_L\bar{w}(\partial L/\partial\tau_L) + \tau_D(\partial D/\partial\tau_L)} \ . \qquad \textbf{(10)}$$

The denominator of (10) is the change in government's revenue due to a marginal change

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9 The household's production possibility frontier is stochastic. However, the aggregate production function is nonstochastic.

10 See Appendix 1 for the derivation of (9).

11 In the case of certainty, Θ collapses to the M term defined in a similar way in Goulder et al. (1996).

in the labour income tax rate, i.e. the partial derivative of (1) with respect to τ_L. The numerator is the welfare change from a marginal change in τ_L.[12] In the absence of uncertainty, welfare changes because (i) labour-leisure decisions are affected and the labour income tax is distortionary; (ii) consumption of the good that generates the externality changes. Under uncertainty, welfare also changes because (iii) of the necessary *risk adjustment* to the expected shadow price of leisure.[13] Assuming risk aversion, the covariance between labour income and marginal utility of consumption is negative.[14] Uncertainty does not only introduce an additional term but it may also affect the sign of the first effect. The sign of the response of leisure to a change in τ_L, $\partial l / \partial \tau_L$, is in general ambiguous and has been shown to critically depend on the presence of wage uncertainty.

Under certainty, the terms in the right hand side of (9) collapse to the three welfare effects identified in the literature as follows. The first is the *Pigouvian effect*, the second is the *revenue recycling effect* and the third is the *tax-interaction effect*. Under uncertainty we have the additional risk adjustment term on the marginal welfare change and the possibility of changing the direction of leisure's response. The combination of these two effects is what we term the *social insurance effect*. This effect is very likely to change the sign of the revenue recycling effect through a change in the sign of the welfare change from a marginal change in τ_L, i.e. the sign of Θ.

IV. Employment-leisure choice under uncertainty

In order to examine the full implications of uncertainty on the interaction between environmental and labour income taxes we examine the effect of a decrease in labour income tax on the household's employment-leisure choice.

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12 Note that within the framework of tax incidence analysis we examine uncompensated changes, i.e. we consider both income and substitution effects. Thus, the term welfare changes is used within this framework.

13 From the first order conditions (4), the first component is $cov\left[U_C, (1-\tau_L)w\right] / E\left[U_C\right] = E\left[MRS_{L,C}\right] - E[w]$.

14 Risk aversion implies $U_{CC} < 0$ and thus, $dU_C / dw = U_{CC}\left[T - l(\tau_D, \tau_L, w)\right] < 0$.

Under certainty, the response of household's choice of leisure to a decrease in labour income tax can be decomposed into an income and a substitution effect. When τ_L decreases after-tax income increases, and thus households move toward a higher level of leisure. At the same time though, the shadow price of leisure increases and as a result households substitute away from leisure. Thus, the overall effect depends on the relative strength of the income and substitution effects. Within a framework very similar to ours, Bovenberg and de Mooij (1994) show that substitution dominates the income effect, i.e. $\partial l/\partial\tau_L > 0$, if the elasticity of substitution between leisure and consumption is greater than one.[15] Under this assumption, there is a marginal welfare cost due to labour income taxation, i.e. $\Theta>0$, and thus the revenue recycling effect is positive.

Under uncertainty, the government has the additional function of providing some type of labour income insurance. A proportional labour income tax, whose revenues are returned to households in a lump-sum form, decreases the spread of the wage distribution while preserving the mean, and thus reduces the level of uncertainty. Contrary to the case of certainty, labour income taxation is not totally distortionary. Therefore, a decrease in τ_L will increase uncertainty which might lead households to choose a higher level of leisure. When this insurance effect is added to the income effect, the likelihood that households will increase leisure in response to a decrease in τ_L is enhanced. As shown in Appendix 2, the possibility that $\partial l/\partial\tau_L < 0$ rises with the degree of households' relative risk aversion with respect to consumption and the share of labour income in consumption expenditure. When labour income is the main source of income, the assumption of moderate relative risk aversion just above unity suffices for $\partial l/\partial\tau_L < 0$. Empirical evidence has shown that the relative risk parameter is above unity (see Friend and Blume (1975)). Furthermore, the literature on wage uncertainty unanimously asserts that an increased wage rate uncertainty reduces labour supply (see for example, Eaton and Rosen 1980a and 1980b, Tressler and Menezes (1980)).

When $\partial l/\partial\tau_L < 0$, a change in τ_L unambiguously yields a marginal welfare benefit. An

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15 Aggregating *D* and *C* into a composite good and maximizing utility, labour supply is expressed as a function of the wage rate and the elasticity of substitution between leisure and the composite good (Bovenberg and de Mooij (1994), p. 1087).

increase in τ_L contributes to the correction of two distortions, the uncertainty in the labour market and the environmental externality, and therefore unambiguously generates an overall benefit. Therefore, $\Theta<0$, and the revenue recycling effect is negative. The overall increase in revenue exceeds the marginal welfare benefit, $-1<\Theta<0$. Thus, the costs of reduced labour income tax revenues, $\tau_L(\partial l/\partial\tau_D)$ exceed the welfare benefits of the labour income tax $\Theta\tau_L(\partial l/\partial\tau_D)$. Although smaller in size relative to the case of certainty, the tax interaction effect is negative.

The above results indicate that, in the presence of uncertainty, the overall welfare effect of environmental taxation is substantially weakened. In addition to the negative *tax interaction effect* we have a negative *revenue recycling effect* due to the *social insurance effect*. An increase in environmental taxation yields only one dividend (the *Pigouvian effect*) which has to be very strong to justify increases in τ_D.

The government in its effort to internalize the environmental externality, reduces work effort and thus, revenue from labour income taxation. Furthermore, if the revenue from the environmental taxation is used to reduce the labour income tax, uncertainty increases and the revenue recycling effect becomes negative. Unilateral increases in one of the policy instruments available to serve the three functions of the government (revenue generation, insurance provision and environmental protection) may lead to welfare losses, especially when strong interaction between the policy instruments exists.

V. Optimal taxation

We have analysed the welfare effect of a marginal increase in the environmental tax, starting from some positive values of τ_L and τ_D. Our results depend on the magnitude of the departure of these initial taxes from their optimal values. Thus, it is important to determine the optimal taxes. Due to the presence of two types of distortions (uncertainty and environmental externality) we analyse optimal taxation within a second-best framework. We also isolate each of the distortions to identify the "first-best" tax rates.

As before, we assume that the government has the same three functions: provide $\bar{G}$, $\bar{\Pi}$, and insurance against wage uncertainty in the form of a transfer Ω. The optimal taxation exercise is to find the combination of labour income and environmental tax rates that along with non-labour income taxation achieve the above three goals at the minimum loss in efficiency. Thus, the government chooses τ_L and τ_D to maximize the household's indirect utility, equation (8). The first order conditions are

$$\frac{\partial u}{\partial \tau_L} = \left(\tau_D - \mu d\right)\frac{\partial D^c}{\partial \tau_L} - \tau_L \bar{w}\frac{\partial l^c}{\partial \tau_L} - \frac{cov\left(U_C, w\right)\left(T - l\right)}{E\left[U_C\right]} = 0 \ , \qquad \textbf{(11)}$$

$$\frac{\partial u}{\partial \tau_D} = \left(\tau_D - \mu d\right)\frac{\partial D^c}{\partial \tau_D} - \tau_L \bar{w}\frac{\partial l^c}{\partial \tau_D} = 0 \ , \qquad \textbf{(12)}$$

where the superscript c indicates income-compensated changes. The change in leisure due to a compensated increase in labour income tax can be negative only when the insurance effect dominates the substitution effect.[16] However, as we approach the optimum τ_L the insurance effect decreases and thus, $\partial l^c / \partial \tau_L > 0$ unambiguously. Assuming leisure and consumption are substitutes, $\partial D^c / \partial \tau_L < 0$. We also have $\partial l^c / \partial \tau_D > 0$ and $\partial D^c / \partial \tau_D < 0$.

In the absence of environmental externalities, starting from zero labour income taxation, an increase in τ_L yields an increase in utility, $\partial u / \partial \tau_L = -cov\left(U_C, w\right)\left(T - l\right) / E\left[U_C\right] > 0$. Thus, the optimal labour income tax is $\tau_L = -cov\left(U_C, w\right)\left(T - l\right) / \left[\bar{w} E\left[U_C\right] \partial l^c / \partial \tau_L\right]$, which becomes zero only when uncertainty is removed, i.e. if $cov\left(U_C, w\right) = 0$. Contrary to the case of certainty, "first-best" is not achieved by setting the labour tax equal to zero and financing public good provision through non-labour income taxation.

Solving the first order condition (12) for the environmental tax yields $\tau_D = \mu d + \left(\bar{w}\tau_L\right)\left[\partial l^c / \partial \tau_D\right] / \left[\partial D^c / \partial \tau_D\right]$. Since under uncertainty the optimal labour income taxation is positive, and assuming that leisure and consumption are substitutes, the optimal environmental tax does not fully internalize the environmental externality, i.e. is less than

16 See Eaton and Rosen (1980a), p. 369-70.

marginal external damages $\tau_D < \mu d$.[17]

Since the optimal environmental tax is smaller than the Pigouvian, the first order condition (11) reveals that the optimal labour income tax, in the presence of corrective taxation, exceeds its first-best counterpart. Since the optimal environmental tax does not completely internalize the externality, the optimal labour income tax is set above its first-best value to supplement reduction in the consumption of the dirty good. Our results give the optimum mix, in a typical second-best manner, of the two policy instruments taking into account the interactions between them.

VI. Conclusions

Our paper re-examines the double-dividend hypothesis in the presence of wage uncertainty. We find that starting from some positive level of environmental and labour income taxation, an increase in the former may have very large welfare costs. Our main result is that welfare costs might be larger within a revenue-recycling policy rather than when the environmental tax revenues are not used to reduce labour income tax. This is in complete contrast with even the most recent literature on double-dividend, which asserts that there is an unambiguously positive effect from recycling environmental tax revenues.

Under uncertainty, first-best requires positive labour income tax, even in the absence of environmental externality. Thus, in the presence of both distortions, interaction between the two policy instruments is unavoidable and therefore we are in a second-best setting. Within this framework, the optimal environmental tax is lower while the optimal labour income tax is higher than their first-best counterparts. Starting from a set of positive taxes below the second-best optimum, we consider the welfare effect of an increase in the environmental tax with the additional revenues used to reduce the labour income tax. First, there is the direct, positive effect of reducing the environmental externality, i.e. *the Pigouvian effect*. Second, revenue recycling reduces the labour income tax further below the second-best optimum, yielding a mean-

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[17] It is interesting to note that similar results have been obtained in the case of imperfectly competitive product markets. For example Buchanan (1969) examines the case of monopoly, Katsoulacos and Xepapadeas (1995) the case of oligopoly, and Constantatos and Sartzetakis (1995) the case of vertical product differentiation.

preserving, spread-increasing change in wage distribution. The resulting increase in households' wage uncertainty is captured by the *social insurance effect*.[18] Thus, contrary to the case of certainty, the *revenue recycling effect* is negative.[19] Third, there is the *tax interaction effect* which is negative since the loss in revenue from labour income taxation[20] always exceeds the marginal welfare benefit from labour income.

Our results indicate that using revenues from an increased environmental tax to reduce labour income tax yields lower welfare. Using the existing terminology, revenue recycling policies are welfare inferior to non revenue recycling policies. This result has very important policy implications. First, as far as it concerns the choice of environmental policy instrument, there is no efficiency advantage of revenue generating instruments over the ones that do not generate revenue, such as grandfathered emission permits. Thus, distributional considerations might once more be the deciding factor in choosing among different instruments. Second, assuming that environmental tax has been chosen, alternative uses of its revenues should be examined. Our research indicates that using the tax revenues in providing "environmental education", an information conveying public good seeking to shift households' preferences away from the dirty good might be a very efficient use of revenues.

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[18] This effect indicates that, contrary to the case of certainty, there is a marginal welfare benefit of labour income taxation and thus, reducing labour taxation has a welfare cost.

[19] A positive revenue recycling effect is possible even under uncertainty, if the initial labour tax is at, or above the second-best. In such case, the risk adjustment term is weaker and the response of leisure to changes in labour income tax is positive. Thus the social insurance effect reverses sign and with it the revenue recycling effect.

[20] Revenues decrease as a result of increased leisure in response to lower real wages as the price of the dirty good increases.

References

K. J. Arrow (1971) “Insurance, risk and resource allocation.” in *Essays in the Theory of Risk-Bearing,* Chicago: Markham.

L. Bovenberg and L.H. Goulder (1996) “Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analysis.” *American Economic Review*, **86**, 985-1000.

L. Bovenberg and R.A. De Mooij (1994) “Environmental Levies and Distortionary Taxes,” *American Economic Review*, **94**, 1085-1089.

J.M. Buchanan (1969) “External diseconomies, corrective taxes and market structure.” *American Economic Review*, **59**, 174-177.

C. Constantatos and E.S. Sartzetakis (1995) “Environmental Taxation when Market Structure is Endogenous: the Case of Vertical Product Differentiation.” *working paper,* Fondazione Eni Enrico Mattei, Nota di Lavoro 76.95

J. Eaton, J. and H.S. Rosen (1980a), “Labour Supply, Uncertainty and Efficient Taxation.” *Journal of Public Economics*, **14**, 365-374.

J. Eaton and H.S. Rosen (1980b) “Taxation, Human Capital and Uncertainty.” *American Economic Review*, 70(4), pp. 705-715.

I. Friend and M.E. Blume (1975) “The demand for risky assets.” *American Economic Review*, **65**, 900-922.

D. Fullerton and G. Metcalf (1996), “Environmental Controls, Scarcity Rents, and Pre-existing Distortions.” *National Bureau of Economic Research, Discussion Paper*, October 1996.

L.G. Goulder (1996) “Efficiency Impact of Pollution Taxes, Quotas, and Permits: The Importance of Pre-Existing Market Distortions.” in *Environmental Economics and Public Policy: Essays in Honour of Wallace E. Oates*. Edited by R. Schwab, Edward Elgar Publishing Ltd.

L.G. Goulder (1995) “Environmental Taxation and the “Double Dividend: A Reader’s Guide.” *International Tax and Public Finance,* **2**, 157-183.

L.G. Goulder, I. Parry and D. Burtaw (1996), “Revenue Raising vs. Other Approaches to Environmental Protection: The Critical Significance of Pre-Existing Tax Distortions.” *National Bureau of Economic Research, Working Paper* # 5641.

Y. Katsoulacos and A. Xepapadeas (1995) “Environmental policy under oligopoly with endogenous market structure.” *Scandinavian Journal of Economics*, **97**, 411-436.

G. D. Myles (1995) *Public Economics*, Cambridge University Press.

W. E. Oates (1993) “Pollution Charges as a Source of Public Revenues.” in *Economic Progress and Environmental Concerns* edited by Herbert Giersch, Berlin: Springer-Verlag.

W.E. Oates (1995) “Green Taxes: Can we Protect the Environment and Improve the Tax System at the Same Time?” *Southern Economic Journal,* **61**, 914-922.

I. Parry (1995) “Pollution Taxes and Revenue Recycling.” *Journal of Environmental Economics and Management*, **29**, S64-S77.

I. Parry (1996) “Environmental Taxes and Quota in the Presence of Distorting Taxes In Factor Markets.” *Resources and Energy Economics,* forthcoming.

I. Parry, R Williams and L. Goulder (1996) “When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets.” *Working Paper, Resources for the Future and Stanford University*, November 1996.

D.W. Pearce (1991) “The Role of Carbon Taxes in Adjusting to Global Warming.” *Economic Journal*, **101**, pp. 938-948.
R. Repetto, R.C. Dower, R. Jenkins and J. Geoghegan (1992) *Green Fees: How a Tax Shift Can Work for the Environment and the Economy*, World Resources Institute, November, Washinghton, D.C.
A. Sandmo (1975) “Optimal Taxation in the Presence of Externalities.” *Swedish Journal of Economics*, **77**, 86-98.
J.H. Tressler and C.F. Menezes (1980) “Labor Supply and Wage Rate Uncertainty.” *Journal of Economic Theory*, **23**, 425-436.
H.R. Varian (1980) “Redistributive Taxation as Social Insurance.” *Journal of Public Economics*, **31**, 237-251.

Appendix 1

Differentiating the indirect utility function with respect to τ_D yields the total effect of a marginal increase in the environmental tax

$$\begin{aligned}\frac{du}{d\tau_D} &= E[U_D]\frac{\partial D}{\partial \tau_D} + E\left[U_C\left(-w\frac{\partial l}{\partial \tau_D} - \frac{\partial D}{\partial \tau_D} + \tau_L(w-\bar{w})\frac{\partial l}{\partial \tau_D}\right)\right] + E[U_l]\frac{\partial l}{\partial \tau_D} + V'\Pi_D\frac{\partial D}{\partial \tau_D} \\ &+ \frac{d\tau_L}{d\tau_D}\left[E[U_D]\frac{\partial D}{\partial \tau_L} + E\left[U_C\left(-w\frac{\partial l}{\partial \tau_L} - \frac{\partial D}{\partial \tau_L} + \tau_L(w-\bar{w})\frac{\partial l}{\partial \tau_L}\right) - (w-\bar{w})(T-l)\right]\right] \\ &+ \frac{d\tau_L}{d\tau_D}\left[E[U_l]\frac{\partial l}{\partial \tau_L} + V'\Pi_D\frac{\partial D}{\partial \tau_L}\right]. \end{aligned} \tag{I.1}$$

Note that $E\left[U_C(1-\tau_L)w\right] = (1-\tau_L)\left[\bar{w}E[U_C] + cov(U_C, w)\right]$. Combining this with the first order conditions (5) and using (7), yields

$$\begin{aligned}\frac{du}{d\tau_D} &= -\left[-V'\Pi_D - \tau_D E[U_C]\right]\frac{\partial D}{\partial \tau_D} - \tau_L\bar{w}E[U_C]\frac{\partial l}{\partial \tau_D} + \left[\left(\tau_D E[U_C] + V'\Pi_D\right)\frac{\partial D}{\partial \tau_L}\right]\frac{d\tau_L}{d\tau_D} \\ &+ \left[-\tau_L\bar{w}E[U_C]\frac{\partial l}{\partial \tau_L} - Cov(U_C, w)(T-l)\right]\frac{d\tau_L}{d\tau_D}. \end{aligned} \tag{I.2}$$

We define $E[U_C]$ as the marginal utility of income and divide both sides of (9). Substituting (3) into (I.2) and rearranging terms yields,

$$\frac{1}{E\left[U_C\right]}\frac{du}{d\tau_D} = \left(\mu d - \tau_D\right)\left(-\frac{\partial D}{\partial \tau_D}\right) + \Theta\left[D + \tau_D \frac{\partial D}{\partial \tau_D}\right] - (1+\Theta)\,\tau_L \bar{w}\frac{\partial l}{\partial \tau_D} , \qquad \text{(I.3)}$$

which is equation (9) in the main body of the paper.

Appendix 2

To describe the effect of labour income tax on work effort, we aggregate clean and dirty goods into a composite consumption good, *Q(C,D)*, where *Q* is homothetic. The utility function is $E\left[U\left[Q(D,C),l\right]\right] + V(\Pi)$. We assume decreasing marginal utility from both the composite consumption good and leisure, $U_{QQ} < 0$ and $U_{ll} < 0$. The first order condition for utility maximization is

$$E\left[U_l\right] = E\left[U_Q\left(1-\tau_l\right)w\right] . \qquad \text{(II.1)}$$

Differentiating the above with respect to τ_L yields

$$E\left[U_{ll}\right]\frac{\partial l}{\partial \tau_L} = E\left[-wU_Q + w\left(1-\tau_L\right)U_{QQ}\left[-w(T-l) + \left(1-\tau_L\right)w\frac{\partial l}{\partial \tau_L}\right]\right] . \qquad \text{(II.2)}$$

Denoting by *R* household's relative risk parameter we rewrite (II.2)

$$\frac{\partial l}{\partial \tau_L} = -\frac{1}{\Delta}E\left[wU_Q\left(1-Rs\right)\right] , \qquad \text{(II.3)}$$

where $R = -U_{QQ}Q/U_Q$ is the degree of relative risk aversion, $s = w\left(1-\tau_L\right)(T-l)/Q$ is the share of labour income in total expenditure, and $\Delta = E\left[U_{QQ}\left(1-\tau_L\right)^2 w^2\right] + U_{ll} < 0$ from the second order condition of the utility maximization problem.